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THE UNIVERSITY OF ALBERTA

VALIDATION OF A PERFORMANCE TEST FOR OUTCOME EVALUATION OF KNEE FUNCTION

BY

SÉRGIO TEIXEIRA DA FONSECA

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **"VALIDATION OF A PERFORMANCE TEST FOR OUTCOME EVALUATION OF KNEE FUNCTION"** submitted by **Sérgio Teixeira da Fonseca** in partial fulfillment of the requirements for the degree of **Master of Science.**

Supervisor.

September 15th, 1989.

ABSTRACT

Thirty subjects were divided into three groups of ten (Control, ACL-deficient and brace groups), then tested in four different tasks (straight running, slalom circuit, figure of eight running, and hop test). The results achieved by the subjects in the slalom circuit and figure of eight running tasks were divided by their time obtained in the straight running task (ratios 1 and 2). All subjects also had their knee ligament laxity tested by the KT-1000® knee ligament arthrometer and their knee functional status assessed by the Lysholm knee scoring scale.

One way analyses of variance were calculated for all the tasks to compare the results obtained by each group, while paired t-tests compared the differences between the brace group when the subjects were tested with and without braces (Generation II® brace). Pearson product moment correlations were also used to examine any relationship between the results obtained in the performance test and the results obtained by the Lysholm knee scoring scale and the KT-1000® knee ligament arthrometer.

The results showed that only the ratio between the figure of eight running time and the straight running time was able to differentiate normal individuals from individuals who sustained ACL injuries. Apart from the hop index, the KT-1000® and the Lysholm knee scoring scale did not correlate with the other performance tasks. The Generation II was effective on improving the performance of the ACL-deficient subjects in the figure of eight and hop tests. However this brace had an adverse effect on the straight running time of the injured subjects.

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CHAPTER I
INTRODUCTION

A. THE PROBLEM

Knee injury is one of the major problems facing athletes who participate in contact sports. De Haven and Lintner (1986) estimated that knee injuries were the most common type of injury among the major sports, ranging from 36.9% of football injuries to 61.8% of basketball injuries.

A major concern among sports medicine professionals regarding knee ligament injuries has resulted in the development of several surgical techniques, as well as rehabilitation procedures, in an attempt to minimize the effects of these injuries. Every year, various studies are published on the results and follow-ups of these procedures (Feagin and Blake, 1983; Giove et al., 1983; Hughston and Barrett, 1983; Tegner et al., 1984; Hawkins et al, 1986; Fowler and Regan, 1987; Sherman et al., 1988; Straub and Hunter, 1988). However, an examination of the published data shows a wide range of rating systems employed. Noyes et al (1985) stated that the differences in the rating systems is one of the major obstacles in comparing studies' results. In addition, some of the methods of measuring the patient's outcome, e.g., patient's subjective analysis, objective clinical tests, strength measurements, and return to sports activities, might not be reliable indicators of the success of surgical techniques and rehabilitation programs (Noyes et al., 1985; Seto et al., 1988; Harter et al., 1988).

Recently, some authors have reported that functional evaluation of the knee is an important factor in the final analysis of surgery and rehabilitation of knee ligament injured subjects (Daniel et al., 1982; Odensten et al., 1983; Harter et al., 1988). As a result, the post-injury performance of subjects sustaining knee ligament injuries has been evaluated in different ways (Arvidsson et al., 1981; Daniel et al., 1982; Lysholm

and Gillquist, 1982; Tegner et al., 1986; Fowler and Regan, 1987; Straub and Hunter, 1988). Return to pre-injury activity level or sport, reinjury data, patient's subjective analysis of the knee function, and performance tests are the functional outcome measurements most commonly used. However, most of the evaluation systems employed are dependent on the patient's subjective analysis or on information which might not be an adequate indicator of the patient's functional status (Seto et al., 1988; Harter et al., 1988).

In order to overcome problems related to the lack of objectivity concerning the assessment of knee function, Tegner et al. (1986) developed a performance test to monitor rehabilitation progress and to evaluate anterior cruciate ligament injuries. Although these authors have stated that the performance test made it possible to obtain an overall view of the knee function, the test was not sensitive enough to detect all the injured subjects.

Because of the necessity of developing measurement tools which could be reliable indicators of the patient's knee function, the present study aimed to create and to validate a performance test that could assess the functional ability of subjects sustaining anterior cruciate ligament (ACL) injuries. Concomitantly, the test was used to assess the effectiveness of a custom made functional brace (Generation II®[1]) in the functional performance of injured subjects. Functional braces are designed to provide stability for unstable knees. Although several investigators have examined the functional braces (Basset and Fleming, 1983; Colville et al., 1986; Baker et al., 1987; Coughlin et al., 1987), there is little objective data regarding the effect of these braces on improving performance.

---

[1]Generation II Orthotics, inc., Vancouver, Canada

B. OBJECTIVES OF THE STUDY

The first objective was to develop and to validate a performance test to obtain precise data on the knee function of ACL-deficient patients. The test did not require any sophisticated equipment and, therefore, could easily be conducted by both clinicians and researchers.

The second objective was to use the test to assess the effectiveness of the Generation II® functional brace in controlling knee instability and improving knee function. Although some investigators have studied the efficacy of knee braces in treating knee instability, none of them addressed the functional aspect of their action in subjects sustaining ACL injuries.

C. RESEARCH HYPOTHESES

This study was an endeavor to examine the following hypotheses:

1. Subjects sustaining knee injuries would spend significantly more time doing the performance test than normal subjects.
2. ACL-deficient subjects wearing a functional brace would spend significantly less time in the performance test than when they were without braces, but more time than normal subjects
3. The results obtained in the performance test would correlate satisfactorily with the Lysholm knee scoring scale.
4. The results obtained in the performance test would correlate satisfactorily with the degree of ligamentous laxity as measured by the KT-1000®[2] knee ligament arthrometer.

---

[2] MEDmetric Corporation, San Diego, CA

D. DEFINITIONS

The following words are defined as they were utilized in this study:

SUBJECTS: Volunteers who fulfilled the inclusion and exclusion criteria and participated in the study.

ACL-DEFICIENT SUBJECT (ACL-DEFICIENT KNEE): Subject sustaining a diagnosed ACL rupture (3° sprain). ACL-deficient subjects met the following criteria: positive Lachman's test, positive anterior drawer sign, a documented pivot shift, minimum valgus opening, no posterior drawer sign and no excessive lateral Slocum test as performed by one orthopaedic surgeon.

KNEE FUNCTION (KNEE FUNCTIONAL STATUS): Functional capability of the knee under dynamic, weightbearing conditions.

FUNCTIONAL DISABILITY: Measure of the limitation imposed upon a patient as a result of an ACL injury.

FUNCTIONAL OUTCOME MEASUREMENT: Measure of the functional capability of subjects sustaining ACL injuries following any type of treatment approach.

ACTIVITY LEVEL: Frequency and type of sport or athletic activity practiced by the subjects. It was divided into four categories modified from Seto et al. (1988).

a) Competitive: participation in a sports activity six to seven times per week and/or regular participation in organized competition or activity of a similar intensity.

b) recreational: participation in a sports activity three to five times per week or two times per week for more than 2 hours per session.

c) weekend: participation in a sports activity two or less times per week with each session lasting approximately 1 hour per session.

d) Sedentary: no participation in sport or activity of a similar intensity.

FUNCTIONAL KNEE BRACE: A brace that was designed to provide stability and to improve function of an unstable ACL-injured knee.

KNEE SCORING SCALE: A document by which a knee was rated on several different parameters in terms of points.

PERFORMANCE TEST: The performance test consisted of four tasks which simulated components of sports activities. These tasks were used to assess the functional performance of individuals sustaining ACL injuries. The tasks were:

a) Straight running

b) Figure of eight

c) Slalom circuit

d) Hop test

MATCHING: A process used to control the extraneous variance of the study. It was executed by defining variables on which the subjects of different groups were matched.

REFERENCE VALUES: The method employed by previous studies on performance tasks to compare normal and ACL-injured subjects. The results achieved by normal

subjects in the performance task were defined as the range of "normal performances" (mean ± 2 SDs), and then used for comparisons. (Tegner et al., 1986)

END POINT COMPLIANCE INDEX (EPCI): One of the recording methods used by this study to analyze the KT-1000® results. The EPCI was calculated by subtracting the anterior tibial displacement obtained with the KT-1000® knee ligament arthrometer at 15 lbs pull from the results obtained at 20 lbs pull.

E. LIMITATIONS OF THE STUDY

The following limitations applied to this study:

1. The study depended on the validity and reliability of the Lysholm knee scoring scale. Lysholm and Gillquist reported that the coefficient of variation of this knee scoring scale was 2%.

2. The study depended on the accuracy of the diagnosis of anterior cruciate ligament deficiency.

3. The comparison between ligamentous laxity and function depended on the accuracy of the KT-1000® knee ligament arthrometer measurements.

4. No information on the subjects' hamstrings and quadriceps strength, knee range of motion, or knee pain were given.

F. DELIMITATIONS OF THE STUDY

1. The study dealt only with the diagnosis of unilateral ACL-injury, and subjects within 15-38 years of age.

2. The test referred only to four specific performance tasks.
   a) Straight running
   b) figure of eight
   c) Slalom circuit
   d) hop test

3. The test results were compared with the Lysholm knee scoring scale, therefore, correlation with other knee scoring scales could not be implied.

4. The study concerned the analysis of the effectiveness of just one functional knee brace (Generation II®).

5. The assignment of subjects to this study was done through a matching procedure. Although the internal validity was controlled, a strong matching represented a threat to the external validity.

CHAPTER II

LITERATURE REVIEW

This chapter focuses on two major topics. The first part of the chapter deals with the disability caused by injuries to the anterior cruciate ligament and the existing methods of assessing the magnitude of this functional loss. The second part is a brief review of functional braces and their effectiveness in improving the performance of subjects sustaining knee ligament injuries

I. FUNCTIONAL DISABILITY IN ANTERIOR CRUCIATE LIGAMENT-DEFICIENT KNEES

The role of the anterior cruciate ligament (ACL) in providing stability to the knee joint has already been demonstrated by several investigators (Girgs et al., 1975; Piziali et al., 1980; Lipke et al., 1981; Cabaud et al., 1983). However, the functional disability produced by an ACL insufficiency has not been well established (Arnold et al. 1979). Fetto and Marshall (1980) described functional disability as a measure of the handicap imposed upon a patient as a result of an injury. This study reported that among 176 ACL deficient patients, at least 92% had some degree of functional limitation as compared with their preinjury state. The magnitude of the functional loss caused by an ACL injury has been reported to depend on several factors, such as neuromuscular skills and meniscal involvement, and might vary from minimal to incapacitating functional disability (Noyes et al., 1985).

It has been reported that subjects with an ACL-deficient knee have an inability or a difficulty performing activities which involved strenuous jumping, rapid deceleration, twisting, cutting and turning situations (Arnold et al, 1979; Fowler and Regan, 1987; Seto et al., 1988). Noyes et al. (1983a) observed that 67% of their patients with ACL

injuries had severe functional disabilities in twisting and turning activities, as opposed to 22% in straight running. Andrews et al. (1977) analyzed the cutting mechanism of individuals when running. It was concluded that subjects with rotatory instability should have no difficulties running, accelerating or decelerating in a straight line. However, additional stress would be placed on the knee ligaments when performing the sidestep and crossover cutting maneuvers. Tibone et al. (1986) examined the performance of ACL-deficient subjects during several activities. Although no differences during walking or running activities were found, they demonstrated a significant difference between limbs during the cross-cutting (crossover) maneuver. In agreement with this result, Czerniecki et al (1988) observed that ACL deficiency did not result in an increase in tibiofemoral rotation during running. These results may explain the greater difficulties found by ACL-injured patients when attempting to return to sports involving cutting than those involving noncutting situations (Seto et al., 1988)

Although injuries to the ACL have been reported to result in functional disability (Arnold et al., 1979; Fetto and Marshall, 1980; McDaniel and Dameron, 1982; Rovere and Adair, 1983), ligaments are not the only structures to provide functional stability. Noyes et al. (1980) reported that:

> " Functional stability occurs when the external forces of activity placed upon a joint are correctly balanced by internal forces provided by neuromuscular system, ligaments and joint contact."

This multi-factor view of knee stability has lead to different treatment approaches to restore the patient's knee function and principally to a diversity of outcome measures to assess the end results of these treatment techniques. However, the relationship between functional disability and some commonly used methods of knee outcome measurement seems to be questionable (Brand, 1986; Seto et al., 1988). Investigators

have recently shown that some of these methods correlated poorly with knee functional performance. (Harter et al., 1988; Seto et al., 1988).

A. KNEE OUTCOME MEASUREMENT METHODS

The main objective of the rehabilitative and surgical approaches to the treatment of anterior cruciate ligament injuries has been to provide the patient with the ability necessary to functionally perform at the same level as his/her preinjury functional status (Odensten et al. 1983; Straub and Hunter, 1986; Seto et al. 1988). In order to verify the effectiveness of different treatment techniques, several methods for outcome measurement have been employed (Lysholm, 1982).

Noyes et al. (1985) stated that the difference in rating systems is one of the major problems in comparing studies. In addition, some of the methods used to assess the success of treatment procedures did not seem to correspond to the patient's functional level (Harter et al., 1988). Jensen et al. (1983) pointed out the excess of "good results" reported in the literature and argued that the lack of critical measurement criteria to evaluate operative procedures results had contributed to this overabundance of "good results". The most commonly used methods for outcome analysis included: return to sport criteria, measurement of quadriceps and hamstrings strength, clinical evaluation of ligament laxity and joint degenerations, and patient's subjective grading of results (knee scoring scale). Each of these criteria will be analyzed in the following sections.

A 1. RETURN TO SPORTS

Studies have shown that functional disability of the knee frequently manifests as limitation of sports activities (Fetto and Marshall, 1980; McDaniel and Dameron, 1983; Fowler and Regan, 1987; Shields et al., 1987). The major complaint of the ACL-injured subject who attempted to resume sports activities has been instability, which has

generally been expressed in terms of a feeling of "giving way" (Lysholm and Gillquist, 1982; Hawkins et al. 1986). Because of the demands imposed by sports and the limitations caused in subjects sustaining ACL injuries, the criteria for returning to sports has been considered as a predictor of the functional outcome in the treatment of ACL-deficient knees. Several investigators have reported the success of their treatment regimen in terms of return to sport (Giove et a., 1983; Hawkins et al., 1986; Fowler and Regan, 1987; Shields et al., 1987; Straub and Hunter, 1988).

Noyes et al. (1985) emphasized that functional disability was activity related and increased in frequency as the activity level increased from walking to recreation and then to strenuous sports. Giove et al. (1983) and Seto et al. (1988) observed that limitation to sports varied according to the type of sport involved. Both studies showed that this limitation was more evident in cutting sports, such as football and basketball, than in non-cutting sports such as bicycling and running. A closer observation of the data provided by both studies revealed that the limitation to sports activities might even vary within the same category of sport, e.g. football (cutting) vs. racquetball (cutting).

Based on existing differences among the functional demands of the several sport modalities, Noyes et al. (1985) stated that return to sports was not a reliable indicator of the success of a rehabilitation program without specifying the patients' sport participation status before and after injury, and the intensity level which they played in each of these circumstances. Giove et al. (1983) reported that although return to sport was the goal of most patients and it might represent their individual success, it was an imprecise method of assessing function. The great variation of demands on ACL-deficient knees given by different sports supported the lack of precision in this criteria. In addition, Harter et al. (1988) observed a poor correlation ($r = 0.11$) between sport activity level and the patient's evaluation of the knee function .

A 2. STRENGTH MEASUREMENT

The importance of thigh muscle strength has been greatly emphasized in the recovery from ACL knee injuries (Jonhson, 1983; Arvidson et al., 1981). Several authors stressed the role of adequate quadriceps and/or hamstring training in the restoration or improvement of the knee function (Giove et al., 1983; Noyes et al., 1983; Walla et al., 1985). Because of the importance of strength recovery in the rehabilitation of the ACL-deficient knee, strength measurements have been used as an adjunct to the assessment of the patient's knee function (Odensten et al., 1983; Seto et al., 1988). However, the results were expressed in different ways: 1) quadriceps strength (Odensten et al. 1983), 2) hamstring strength (Walla et al., 1985), 3) both measures (Tegner et al., 1984; Giove et al., 1983; Arvidsson et al., 1981; Kannus and Järvinen, 1987a), 4) hamstring-quadriceps ratio (Murray et al., 1984; Giove et al., 1983).

Although it has been reported that good muscle function could mask the loss of the ACL (Kannus and Järvinen, 1987a), there is still some controversy concerning the relationship between muscle strength and patient's functional status. Studies carried out by Tegner et al. (1984) and Odensten et al. (1983) have shown an increased functional level with an increase in muscle strength. Other investigators also observed that subjects with greater muscle strength were able to perform at a higher level than those with less strength (Giove et al., 1983; Arvidsson et al., 1981). Conversely, Murray et al (1984) stated that the degree of strength deficit did not correlate with the need for surgery. It was found that the improvement of strength was not able to diminish the patients' symptoms.

Seto et al. (1988) analyzed results of intra-articular and extra-articular surgical procedures and observed that a significant relationship between thigh muscle strength and functional status was only noted in the intra-articular group. It was suggested that function related not only to a decrease in quadriceps strength, but also to the degree of

that strength deficit. Recently, Harter et al. (1988) reported that quadriceps and hamstring maximum torque was not significantly correlated to measures of knee function (r= .07 to .24)

The importance of muscle thigh strength for successful rehabilitation of the ACL-deficient knee was evident from the literature (Giove et al., 1983; Tegner et al., 1984; Odensten et al., 1983; Jonhson, 1983; Noyes et al., 1983b). However, a direct relationship between muscle strength and improved functional performance could not be established (Murray et al., 1984; Walla et al., 1985; Seto et al., 1988). Criteria using strength measurements to allow return to full activities after ACL injuries, as used by Giove et al. (1983), should be carefully analyzed, since muscle strength may not always be a reliable indicator of the patient's functional status (Seto et al., 1988; Harter et al., 1988).

A 3. CLINICAL EVALUATION OF LIGAMENT LAXITY

Instabilities following knee ligament injuries have been subject of several investigations (Hughston et al., 1976; Arnold et al., 1979; Noyes et al., 1983a). Studies have demonstrated the efficacy of specially designed tests in identifying ligament deficits. (Losee et al., 1978; Marshall and Baugher, 1980). Positive ligamentous tests such as Lachman, anterior drawer, and pivot shift have been shown to correlate with diagnoses of ACL injuries (Katz and Fingeroth, 1986; Gurtler et al., 1987; Jakob et al., 1987). Because of the relationship between assessment and ligament injury, ligamentous tests have been used to evaluate the ultimate success of surgical procedures (Kannus and Järvinen, 1987b; Shields et al., 1987; Straub and Hunter, 1988; Seto et al., 1988).

The positiveness of clinical tests has been classically described as mild (1+), moderate (2+) and severe (3+). (Hughston et al., 1976). Since the above classification relies on the examiner's perception, ligamentous tests have been considered as

subjective and inaccurate (Feagin and Blake, 1982; Oliver and Coughin, 1986) In order to overcome this subjectivity, instrumented knee ligament analysis has been suggested (Daniel et al., 1985; Weesner et al., 1987). Devices ,such as KT-1000®, KT-2000®[1], and Genucom®[2] knee arthrometers, have been shown to provide objective and reliable data on knee ligament laxity (Daniel et al., 1985; Oliver and Coughin, 1986). These devices quantify the amount of anterior or posterior tibial displacement with respect to the femur at a known force. The KT-1000® is the knee arthrometer most commonly used to measure knee laxity. Despite its popularity, several factors, such as knee flexion angle, muscle relaxation,and knee rotation angle, have been reported to affect the arthrometer measurements (Malcom et al., 1985). Furthermore, the forces at which the KT-1000® or KT-2000® assess knee laxity (15 to 20 lbs) do not represent the forces that are imposed on the knee during athletic activities (Noyes et al., 1980). Thus, despite the improvement from clinical tests, the results provided by these instruments may not represent a real life situation.

Although tests of knee stability are often used to estimate the knee postoperative status, the relationship between function and stability has not been well established (Harter et al., 1988). Jensen et al. (1983) found a positive correlation between success of surgery and the amount of postoperative anterolateral instability (pivot shift). Furthermore, Odensten et al. (1983) observed that patients with unstable knees complained of significant symptoms of instability and achieved low scores in a knee function test. In contrast, Shields et al. (1987) stated that functional disability experienced by patients did not directly relate to the amount of clinical instability measured. Finally, Fowler and Regan. (1987) and Seto et al. (1988) found no correlation between functional activity results and stability tests (Lachman, anterior drawer and pivot shift tests)

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[1] MEDmetric Corporation, San Diego, CA
[2] FARO Medical Technologies Inc., Montreal, Canada

A more comprehensive explanation on the relationship between a clinical test and function was conducted by Harter et al. (1988). It was concluded that patient's perceptions of postoperative knee status were independent of the results of static and dynamic clinical tests commonly employed to assess knee stability. Although clinical stability might be important for a satisfactory knee performance, it was not the only factor playing a role in the overall knee function (Noyes et al. 1980). It has been shown that stable knees were more likely to perform at higher levels (Odensten et al., 1983), However, the lack of knee stability did not implicate in poor functional outcome (Shields et al., 1987; Fowler and Regan, 1987; Seto et al., 1988; Harter et al., 1988).

A 4. SUBJECTIVE GRADING OF RESULTS (KNEE SCORING SCALE)

Odensten et al., (1983) has reported that the functional disability experienced by patients during activities could be registered on a scoring scale. Knee scoring scales are questionnaires designed to establish the patient's knee function in everyday situations (Kettelkamp and Thompson, 1975; Lysholm and Gillquist, 1982).

The knee scoring scale has been one of the most commonly used reporting devices (Feagin and Blake, 1983). However, several different scales have normally been employed, resulting in difficulties as to the comparison of results (Noyes et al., 1985). The Lysholm scoring scale (Lysholm and Gillquist, 1982), the hospital for special surgery scale (Marshall et al. 1977), and the knee function rating form (Noyes et al, 1985) were among the most widely used knee scoring scales. These scales relied on the patient's self-assessment of function and, therefore, represented a subjective evaluation.

Harter et al. (1988) described the subjective knee rating scale as the most reflective factor of knee function following ACL reconstruction. Tegner and Lysholm

(1985) suggested that knee scoring scales gave a satisfactory picture of the patient's knee function when no restriction was given to the patients. However, the authors stated that the use of a knee scoring scale for monitoring rehabilitation could be inadequate, since the restriction imposed by the rehabilitation program might affect the results. Moreover, self-assessment of function depended on the patient's expectations and on his/her desirable activity level. Noyes et al. (1983) mentioned that athletically active populations willing to return to full activities could underestimate their functional status, once they conceived of themselves as having a greater functional loss than actually existed. Conversely, Odensten et al. (1983) outlined that results of scoring scales did not always represent the real functional level of the patient. It was pointed out that patients with reduced activity level were more likely to overestimate their knee function and therefore achieve a falsely high score. Similar results were found by Tegner and Lysholm (1985), who reported that low activity level might mask the functional status of a patient in a knee scoring scale. Despite their popularity, knee scoring scales still present some weaknesses and, therefore, their results must be carefully analyzed.

A 5. PERFORMANCE TESTS

As previously mentioned, one of the most common functional evaluations of knee ligament surgery and rehabilitation programs has been to observe the return of the patient to sports activity (Daniel et al., 1982; Seto et al., 1988). Because of the great variation among sports, this evaluative method has been described as inaccurate (Noyes et al., 1985). Performance tests which simulate components of sports have been devised to evaluate functional losses after ligament injuries (Daniel et al., 1982; Tegner et al., 1986). These tests provide objective data that can be quantitatively measured. To date, only a few studies have used performance tests to evaluate the functional status of

subjects sustaining knee injuries (Daniel et al., 1982; Odensten et al., 1983; Tegner et al., 1986; Elmquist et al., 1988).

Daniel et al. (1982) described a timed functional test (40 yard shuttle run) which involved acceleration, deceleration, and reversal of direction situations. Forty seven normal male and 47 normal female volunteers performed the test and the range of each group was used to define the limits for normal subjects (satisfactory). It was later observed that 74% of 300 patients had a satisfactory outcome in this performance test in comparison to 59% in a sport performance assessment. Another test described by Daniel et al. (1982) was the hop index, in which the subjects standing on one leg took one hop for distance and landed on the same leg. The results were taken as the deficit between the distances achieved by the normal and affected legs. The authors exalted the practicability of the test that could be performed in a short area. In this test, however, 79% of the patients had satisfactory grades, showing that the hop test identified fewer subjects with ACL deficits than the 40 yard shuttle run. Odensten et al. (1983) analyzed the performance of 66 patients with anterolateral knee instability in a figure of eight running task. The running time was found to be significantly correlated to quadriceps and hamstring strength. In addition, it was noted that subjects with a score of over 77 points in a knee function scale assessment (Lysholm knee scoring scale) had a significant shorter running time than those with fewer points.

Tegner et al. (1986) carried out the only study which specifically dealt with a performance test. Four different tasks were described: one leg hop, running up and down a slope, running up and down a staircase, and running a figure of eight. A group of normal subjects were tested to obtain the reference values for comparisons with the ACL-injured group. A normal result was defined as being a performance within the reference range (mean ± 2 SDs). It was observed that only 35% to 46% of ACL-deficient subjects performed normally on the turn of the figure of eight, stair running,

and on the slope running, whereas most of the patients achieved normal values in straight running and one leg hop. Analysis of the test reliability showed a coefficient of variation between 1.6% to 5.7% in the test tasks. Elmquist et al. (1988) used the same test devised by Tegner et al to evaluate the final results of ACL reconstructions. The study's own reference value was determined in 30 normal subjects. The performance test was reported to be normal in 23 of the 29 patients. It was interesting to note that all six patients who had one or more abnormal values in the test were considered excellent or good when using the Lysholm knee scoring scale.

Tegner and Lysholm (1985) reported that knee performance tests provide objective measures of function in sportslike activities, but the analysis is restricted to a short test evaluation, which may not correspond with the real condition of the patient. Furthermore, Tegner et al. (1986) stated that a performance test, with several items that stress the leg in different ways, may obtain an overall view of the knee function, provided that the rest of the leg is normal. However, comparison between the reference values obtained in the studies by Tegner et al. (1986) and Elmquist et al. (1988) showed that the results in a performance test may widely vary even among normal subjects. This variation indicated that there was an effect of individual abilities on the running time of the test. Since ACL injury did not greatly affect straight running (Tibone et al., 1986; Czerniecki et al., 1988), subjects with abnormal knee function might achieve normal results if they had a shorter straight running time in the performance tests.

II. FUNCTIONAL KNEE BRACES

Along with several surgical techniques or rehabilitation regimens, functional braces have been frequently employed in sports medicine as part of the treatment of patient with ACL deficiency. Functional knee braces refer to a group of braces that are intended to control the instability caused by knee ligament injuries and to improve the

patient's performance. However, the question whether functional braces are effective or not still remains to be answered.

Although several investigators have examined the functional braces (Basset and Fleming, 1983; Colville et al., 1986; Baker et al., 1987; Coughlin et al., 1987), little objective data regarding their effectiveness on improving function of ACL-deficient subjects, have been provided by these studies. Most of the literature addressing functional braces have examined their action in reducing ligament laxity, rather than their effect on knee function (Basset and Fleming, 1983; Beck et al., 1986; Coughlin et al., 1987). In addition, other studies investigated biomechanically the effect of the braces on stability (Baker et al., 1987; France et al., 1987; Paulos et al., 1987). Despite the important information on the biomechanical behavior of functional braces provided by these studies, the functional aspects affecting the performance of injured subjects was not mentioned.

As previously presented in this chapter, measurements of knee function were frequently based on subjective or, sometimes, unreliable data. The analysis of the functional role of the braces has also been greatly based on subjective information provided by the patient (Basset and Fleming, 1983; Hawkins et al., 1986), or on return to sport criteria (Colville et al., 1986; Coughlin et al., 1987). These studies, as well as the studies focussing on the effect of braces on ligament laxity, reported controversial results on the braces effectiveness. Despite the fact that most of the studies observed some benefits of functional braces in subjects sustaining knee injuries, no uniform conclusion could be drawn from them.

Only a few studies have dealt specifically with the functional analysis of brace effectiveness (Houston and Goemans, 1982; Prentice and Toriscelli, 1986; Tegner et al., 1988). These studies used some form of performance test to assess the braces, but only Houston and Goemans (1982) examined subjects who had sustained knee ligament

injuries. Houston and Goemans (1982) noticed a marked performance reduction in subjects wearing functional braces. The authors suggested that the benefits of braces in reducing instability were caused by impairing the performance of the patients in their activities. This study, however, considered in the performance test only situations which did not require rotational movements of the knee. Therefore, no real analysis of instability reduction could be made.

Prentice and Toriscelli (1986) observed that functional braces tended to have an adverse effect on straight running, but no detrimental effect on agility. The authors examined only normal subjects and no reference on injury prevention was given. Finally, Tegner et al (1986) examined the effect of derotation (functional) braces on knee motion. This study compared five different braces in different performances tasks, ranging from strength measurements to a figure of eight running. The authors found that functional braces had a desired effect on reducing tibial rotation of the knee without impairing performance. However, this positive effect was highly dependent on the design of the brace tested.

To date, no study has examined the effect of functional braces on the performance of subjects sustaining knee ligament injuries in situations, such as turning and cutting, which require proper functioning of the knee joint.

III. SUMMARY

In the recent decade, much has been written on the function of the anterior cruciate ligament and the functional disability caused by its loss. (Fetto and Marshall, 1980; Noyes et al., 1983; Arnold et al., 1985). Because of this increasing interest, many researchers have created and presented their results of knee surgery and rehabilitation programs (Giove et al., 1983; Hughston et al., 1983; Feagin and Blake,

1983; Tegner et al., 1984; Straub and Hunter, 1988; Hawkins et al., 1986) Their methods of evaluation have been equally numerous.

The difference in outcome measurement methods was one of the major problems in comparing studies (Noyes et al., 1985). In addition, all these methods used to assess the success of treatment programs have weaknesses and some of them do not correspond to the patient's functional status (Harter et al., 1988; Seto et al., 1988). The most commonly used outcome measures included: return to sport criteria, thigh muscle strength, clinical evaluation of ligament laxity, patient's subjective grading of results, and performance tests.

Return to sport has been considered as a predictor of functional outcome in the treatment of ACL-deficient knees. However, the patient's ability and desire to compete in sports, and the differing levels of competition, make sports participation a highly subjective criterion (McDaniel and Dameron, 1983). Because of the importance of strength recovery in the rehabilitation of the ACL-deficient knee, strength measurements have been used as an adjunct to the assessment of the knee function (Odensten et al., 1983). Criteria for using this measurement method should be carefully analyzed, since muscle strength may not always be a reliable indicator of the patient's functional status (Seto et al., 1988; Harter et al., 1988). Although stability ,which is clinically measurable by ligamentous laxity tests, was important for a satisfactory knee performance, its absence did not result in poor functional outcome (Seto et al., 1988; Shields et al., 1987; Fowler et al., 1987). The patients expectations on his/her functional performance after surgery was a real obstacle to the use of knee scoring scales when assessing functional outcome (Noyes et al., 1983a; Odensten et al., 1983). Therefore, results of a knee scoring scales must be interpreted with caution, in spite of the popularity of the scales. Performance tests are still in the development stage. The

results presented so far indicate that this method still has some faults which need to be overcome in order to produce more accurate results.

Along with several treatment techniques, functional braces are frequently employed in sports medicine as part of the treatment of patient with ACL deficiency. The same methods used to assess the outcome of rehabilitative or surgical approaches are also employed in the analysis of the effectiveness of functional braces. The different methods used to evaluate the effectiveness of functional braces have presented somewhat conflicting results. Despite the fact that most of the studies observed some benefits of functional braces in subjects sustaining knee injuries, no uniform conclusion could be drawn from them.

No method currently used for knee outcome measurement is without problems. In addition, the present lack of standardization of measurement methods hampered comparison of results. Careful analysis of the patient's profile, and improvement of the methods described might help to increase the accuracy of the results.

CHAPTER III

MATERIALS AND METHODS

A. INTRODUCTION

Performance tests have been used recently to evaluate post-treatment knee function (Daniel et al., 1982; Tegner et al., 1986; Elmquist et al., 1988). However, their validity has not been well established. In order to assess the practicality as well as the possible problems of this measurement method, two pilot studies were carried out. The observations taken from these pilot studies and the description of the study methodology follows.

B. PILOT STUDIES

Two pilot studies were carried out to observe the feasibility of the test. The first study was performed in a 20 meter long figure of eight and a slalom circuit running track. Five normal subjects were analyzed and the results compared with that of one subject who had sustained ACL injury.

The second study was comprised of a 16 meter long figure of eight and a slalom circuit. One normal and one ACL-deficient subject were analyzed on this occasion. It was observed that the 20 meter long test presented the greatest difference between normal and injured subjects, since it allowed the development of greater speeds before the turning and cutting maneuvers of the test. Thus, the longer tasks imposed a greater degree of difficulty on the subjects with ACL injury.

Another important observation was that subjects who had more velocity in the straight line running, performed the turn of the figure of eight in a greater diameter. Conversely, slower subjects tended to make the turns inside the defined running track,

resulting in a even smaller curve diameter. The second pilot study showed that this problem could be solved by using markers around the whole turn of the figure of eight.

An effective performance test should include situations where the functional disability caused by an ACL-deficiency is evident, e.g. turning, cutting, pivoting. Finally, the studies showed that injured subjects with normal results in the figure of eight and slalom circuit tests might turn out to be relatively slower when their time in these tests are divided by the time obtained in the straight running task.

C. THE STUDY

C 1. Subjects

In the present study, three different groups were analyzed: two groups of subjects sustaining knee injuries and one of subjects with normal knee function. Since this study dealt with specific populations, no randomization procedure was performed. To control the effect of a possible extraneous variance, matching of relevant variables among groups' subjects was used. The variables matched were: 1) sex; 2) age; 3) activity level; 4) weight; 5) height.

Kerlinger (1986) outlined the problems of finding sufficient subjects if matching more than two variables. In order to have realistic parameters the matching process was applied in terms of relatively broad category ranges. The range of each category, or variable, was defined as follows:

- AGE: 15-19, 20-24, 25-29, 30-34, 35-39...
- SEX: male and female.
- ACTIVITY LEVEL: competitive, recreational, weekend, and sedentary.
- WEIGHT: the weight difference between matching pairs was not greater than 20%.

• HEIGHT: The difference between matching pairs did not exceed 5 inches in height.

The criteria for category definition were based on ranges in which the differences were not expected to affect the test results. The inclusion criteria and characteristics of subjects in each group were:

GROUP I (ACL-deficient): Ten subjects with a clinically diagnosed ACL-deficient knee. The diagnosis of the ACL injury was based on the following criteria as determined by one expert orthopaedic surgeon: positive Lachman's test, positive anterior drawer sign, a documented pivot shift, minimum valgus opening, no posterior drawer sign, and no excessive lateral Slocum test.

These subjects had injuries that were not surgically repaired. In addition, they sustained the injury for a minimum of six months and a maximum of five years from the time of participation in the study. This procedure assured that neither acute injuries nor severe knee degenerative disorders were included in the study. Subjects who used functional braces only preventively in sports such as skiing, but participated in pivoting activities regularly without braces, were included in this group.

GROUP II (Brace): Group II consisted of ten subjects with clinically diagnosed unoperated ACL injury who needed to wear functional braces for all athletic activities. The diagnosis of ACL injury followed the same criteria as above. Again the injury time range of six months to five years was observed.

GROUP III (Control): Ten healthy subjects without past history of knee injuries.

The exclusion criteria were:

1. Any subject sustaining another lower limb injury which might alter his/her performance in the test.
2. Bilateral knee injuries.
3. Subjects with multi-directional instability determined by an excessively positive lateral Slocum test and presence of an accentuated valgus opening
4. Subjects with an associated posterior instability determined by a positive posterior drawer sign.

C 2. Equipment

Knee Scoring Scale

A knee scoring scale for evaluation of knee ligament surgery results developed by Lysholm and Gillquist (1982) was employed in this study. It consisted of a eight item questionnaire with different scores for each item. The maximum score was 100 points. The scale emphasized signs and symptoms of instability during selected activities. All items but one (thigh atrophy) consisted of subjects' self assessment of function (Appendix 1).

The use of the Lysholm scoring scale in the present study was based on the fact that it had been used in several previous studies (Odensten et al., 1983; Tegner et al., 1984; Kannus and Järvinen, 1987; Kannus, 1988), allowing, therefore, further comparisons of results. In addition, Lysholm and Gillquist (1982) had examined this scale and reported that their rating system was positively correlated with the subjects' own opinion of function. The test was reported to have a coefficient of variation of 2.8%. However, no other reliability or validity studies have been conducted.

Photoelectric cells

The running time of each subject was recorded by a timer which was triggered by photoelectric cells. The equipment consisted of a digital timer connected to a pair of photoelectric cells by two (on and off) pin jacks (Figure 1). The cells were placed at two different locations in each test task. The first cell provided the "on input" to the timer and was positioned at the start point of each task, while the other cell placed at the end line of each task provided the "off input" to the timer. The timing system had been previously adjusted to provide accurate measures of time in the test tasks.

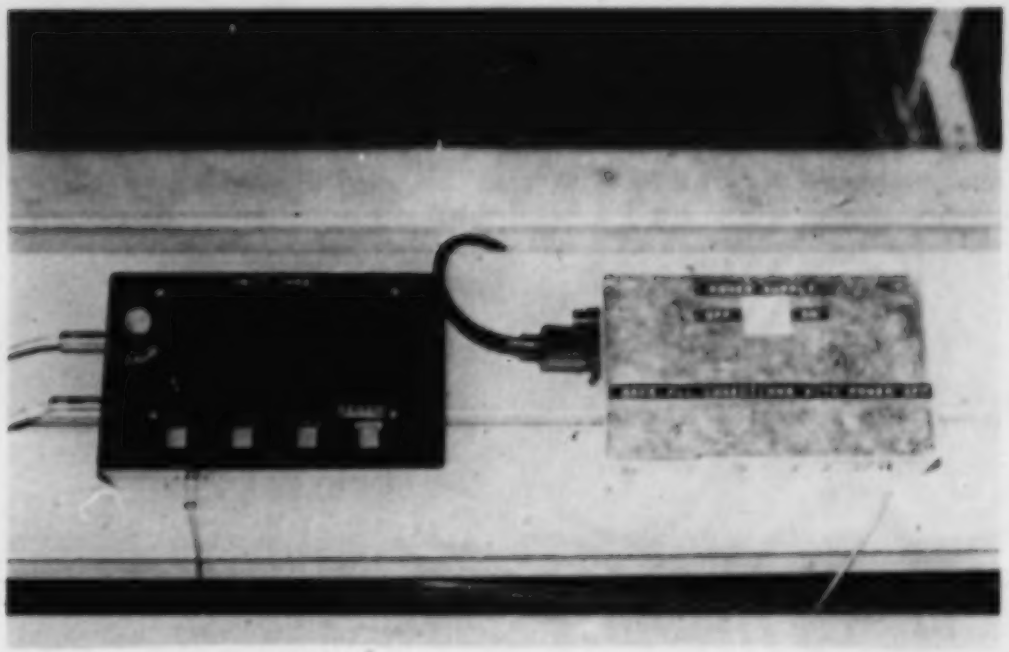


Figure 1: Photoelectric cell for time measurement

KT-1000® knee ligament arthrometer

The KT-1000® knee arthrometer was an objective method of measuring the laxity of the anterior and posterior cruciate ligaments. This method had been reported to produce reliable results (Daniel et al., 1985). The KT-1000® was a portable device

which attached anteriorly in the lower leg. The examiner exerted a monitored force (15 lbs or 20 lbs) by pulling or depressing a handle located distal to the joint line. The instrument quantified the relative motion between two motion-sensing areas in millimeters. Thus, the KT-1000® knee ligament arthrometer indicated the amount of anterior or posterior tibial displacement in relation to the femur (Figure 2).

Two different measures were taken for each subject and used for analysis. The first measurement quantified the difference in anterior tibial displacement between the injured and normal legs when the tester exerted a force of 20 lbs. The second recording method employed was called end point compliance index (EPCI) (Harter et al., 1988). The EPCI was calculated by subtracting the anterior tibial displacement obtained at 15 lbs from the results obtained at 20 lbs. Only the injured leg was considered when calculating the EPCI.

Figure 2: KT-1000 knee ligament arthrometer

C 3. Procedure

The procedures were explained to the subjects and informed consent obtained prior to their participation in the study (Appendix 2). The study participants were tested in the following order: 1) KT-1000® knee ligament arthrometer, 2) Lysholm knee scoring scale, and 3) Performance test.

a) KT-1000®

All subjects had their ligamentous laxity measured by one expert orthopaedic surgeon, previously trained, using the KT-1000® knee ligament arthrometer. The description of the methodology employed for the KT-1000® measurements is presented in the Appendix 3.

b) Lysholm Knee Scoring Scale

The Lysholm scoring scale was administered by a person not involved with the research and the scores were unknown to the main researcher. All the subjects were instructed how to fill out the questionnaire and any questions were promptly answered. The individual score of the eight items in the scoring scale were taken and the total score calculated.

c) Performance Test

The performance test was developed to assess the performance level of subjects sustaining ACL injuries. The test involved recording the time spent and distance achieved by subjects while executing four different tasks. The first three tasks were timed events involving straight running, figure of eight running, and slalom circuit. The fourth task involved measuring the distance achieved when the subjects hopped forward once on one leg. The tasks were devised to simulate some components of sports

activities. The three timed test tasks included turning, jumping, cutting, acceleration, and deceleration situations, all of which placed great demands on ACL-deficient knees. Because of previous observations in the pilot studies, these tests were carefully designed to allow enough space for velocity development in the straight running of the test. In addition, they were not too long to cause difficulties in their preparation or to require satisfactory endurance levels for optimal performances. The tasks were performed indoors, on an artificial surface. In order to prevent injuries to the test participants, spotters were available for each of the tasks.

All subjects were properly dressed for the test. The use of adequate running shoes and shorts (or other running outfit) was obligatory. A ten minute warm-up on a ergometric bike was given before the test to ensure optimal and safe performances (Tegner et al., 1986). Furthermore, the subjects performed one running practice in each of the three stations of the test in order to become familiar with the tasks.

Group II (Brace) performed the test with and without a brace, with the order of each task being randomized. Thus, some subjects started the performance tasks with brace while others started without it. Randomization concerning the order of the tasks was also applied. A three minute rest period was given for all subjects between each task. Any subject failing to complete the tasks due to external factors, such as slipping or giving way, was given a second chance, provided that no injury occurred. The tasks were:

Task One - straight running:

A ten meter long straight running track was set up for task one A minimum space of 10 meters was given for deceleration after the end line, allowing the final speed to be representative of the subjects' capability. Therefore, this task did not measure the

deceleration component of the run. The photoelectric cells were placed on the start and end lines as described previously (Figure 3).

Each subject being tested was positioned at the starting line, with his/her foot placed on the line for a standing start. The subjects were told to wait for the starting signal and then run as quickly as possible. Due to the short duration of the test, the subjects may not have been tested at full speed. Subjects were also asked to avoid any forward movement before the starting signal, in order to avoid triggering the timer before the test started. No encouragement was given to the test participants during the run. The running time was recorded at the finish line. Group II (brace group) performed this task with and without brace.

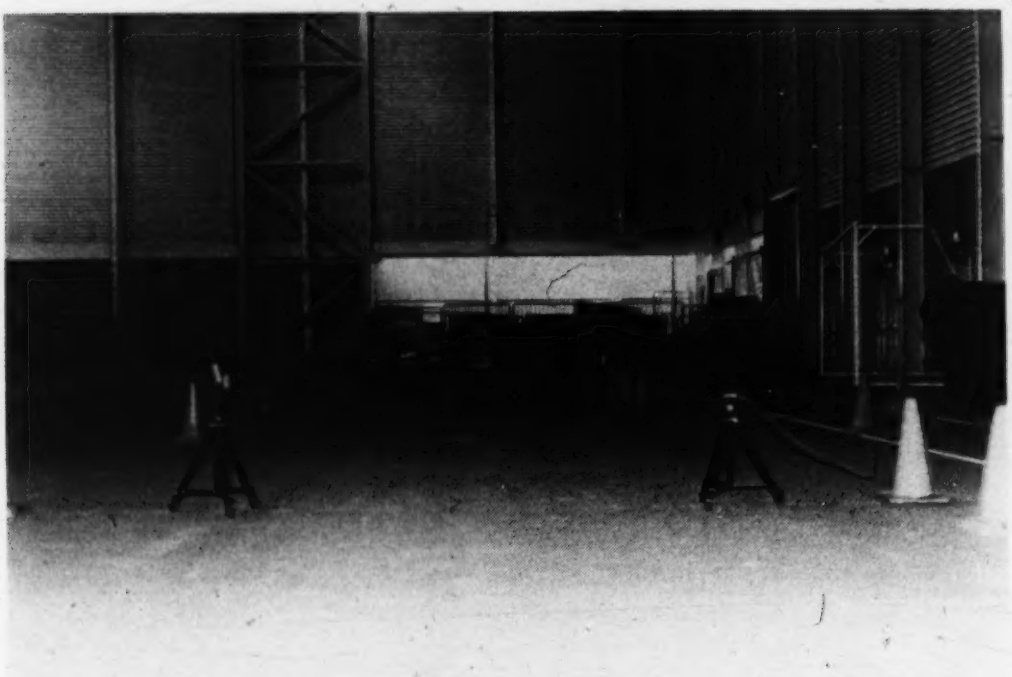


Figure 3: Straight running task cells placement

Task Two - running a figure of eight:

A twenty meter long running track in a figure of eight format was specifically prepared for task two. The diameter of both curves were equal to 4 meters (Figure 5). High markers were used to prevent the subjects from executing the turns in a shorter diameter than that stipulated. The starting point was located at two meters from the beginning of one of the straight lines of the running track. The photoelectric cells were placed 1 meter apart with the "on" cell located over the starting point and the "off" cell at 1 meter from the beginning of one of the straight lines of the running track (Figure 4)

The test required the subjects to have the ability to make long turns in both directions, as well as accelerations and decelerations. Moreover, it was reported not to depend on general skills such as coordination and balance (Tegner et al. 1986).

The subjects were placed with one of their feet on the starting point for a standing start and asked to avoid forward movements. At the starting point, they waited for the starting signal and then ran as quickly as possible. No encouragement was given to the test participants during the run. The running time was recorded as soon as they completed the first lap. Group II performed this task with and without brace.

Task Three - running a slalom circuit:

A slalom circuit was prepared for task three. It was twenty meters long with five turns in its running track (Figure 6). The distance between turns was four meters. Markers were carefully placed in each turn with the turn being an angle equal to 60 degrees. A slow down space was provided in each one of the turnings and at the end of the circuit. The photoelectric cells were placed diagonally at the starting ("on") and ending ("off") lines (Figure 7).

Task three was designed to require fast accelerations, fast deceleration and sharp turns without jeopardizing the knee joint integrity. Since it was a task of short duration, general conditioning did not interfere with the results.

Subjects were positioned at the starting point with one of their feet placed on the line for a standing start. The subjects were, again, told to avoid any forward movement before the starting signal. They were asked to run as quickly as possible when the starting signal was given. They were also instructed to cut without crossover, and not run a circle, in each of the circuit turnings. No encouragement was given to the test participants during the run. The running time was recorded as they crossed the finish line. Group II performed this task with and without brace.

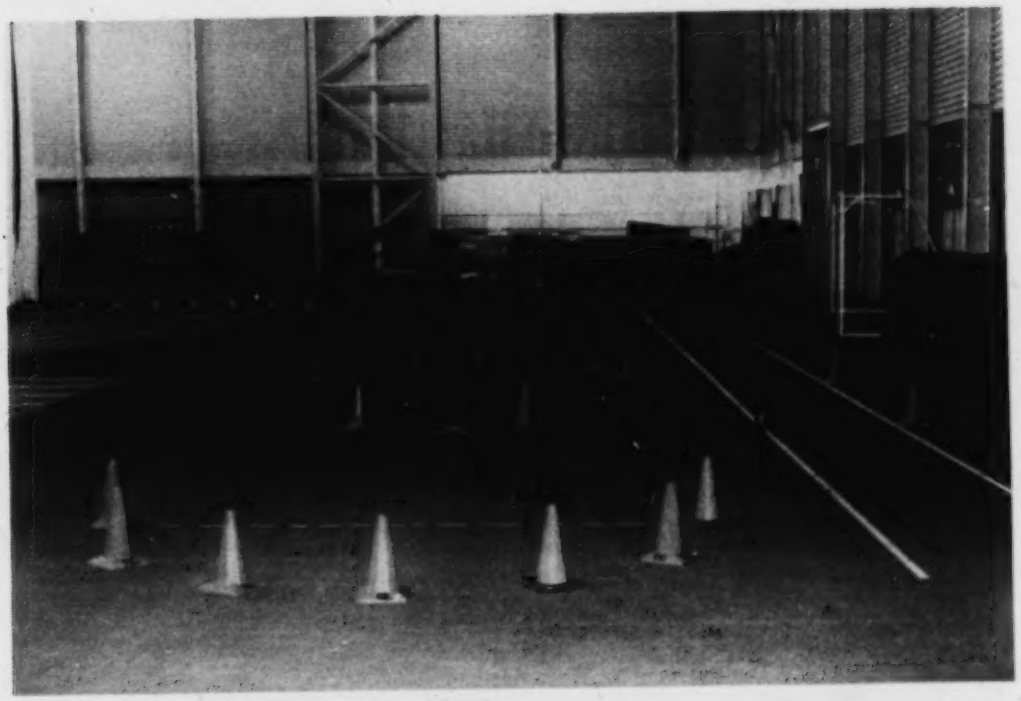


Figure.4: Figure of eight task cells placement.

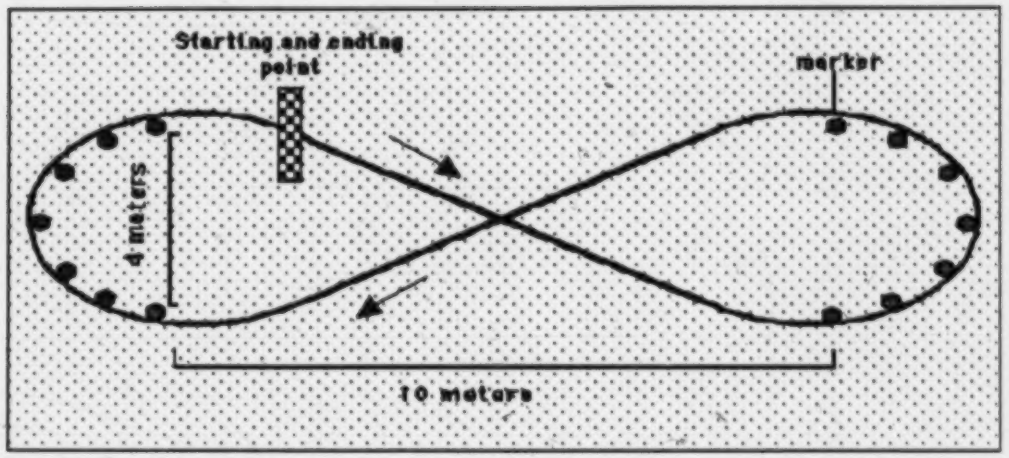


Figure 5: Diagram to illustrate the figure of eight running track.

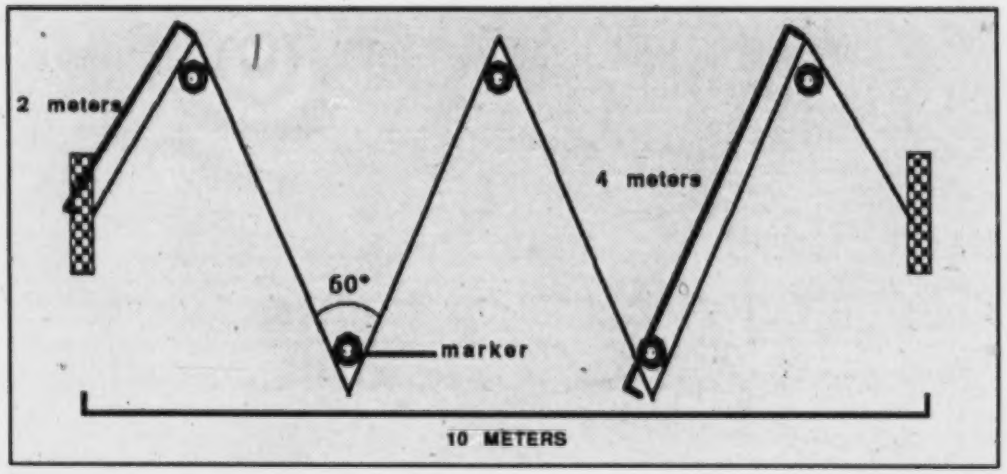


Figure 6: Diagram to illustrate the slalom circuit

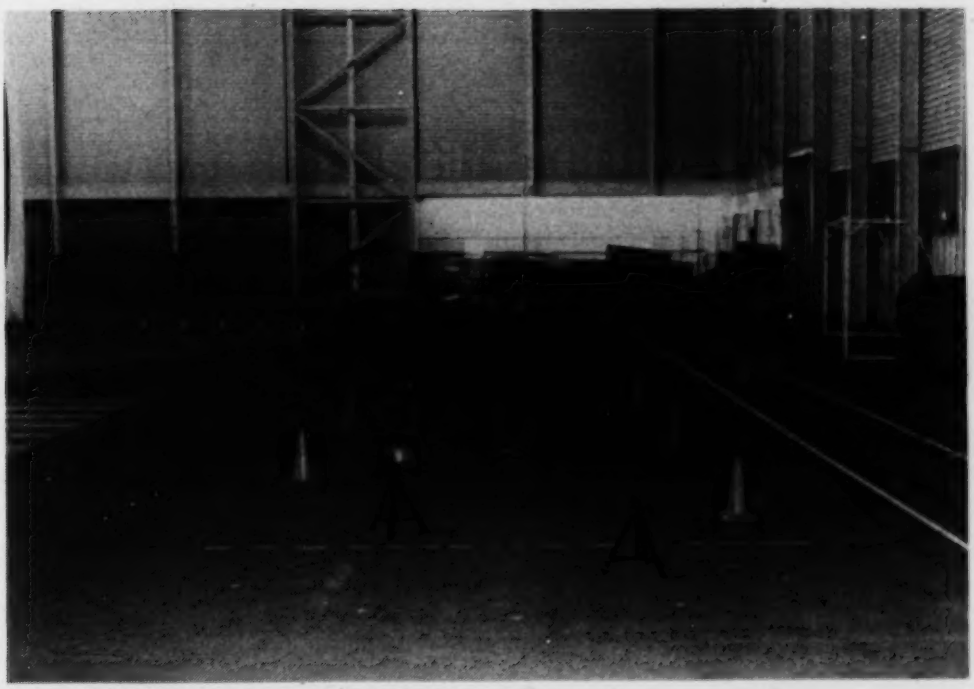


Figure 7: Slalom circuit task cells placement

d) Task Four - the hop test:

The hop test was performed in a four meter area, where a line served as the starting point. Standing on one leg with the middle of the foot of the leg being tested on the line, the subjects hopped once for distance landing on the same leg (Figure 8). Two testers positioned at each of the subject's sides were responsable for marking the distance achieved on the floor with chalk. The subjects performed the test three times with each leg and the best distance for the injured and normal leg was recorded. Group II performed this task with and without brace.

The hop test required strength and confidence in the injured knee to land on the leg after a long hop. Moreover, this test could easily be performed in any clinical setting (Daniel et al., 1982).

Figure 8: Hop test

C.4. Data Management

The results achieved in the first three performance tasks were converted into the ratio between the functional tasks time (the figure of eight and the slalom circuit) and the straight running time. This procedure was based on the study by Tegner et al. (1986) who reported that injured subjects spent more time executing tasks which require turnings situations than normal individuals, whereas the straight running time was the same for both groups. Thus, if the running time in the functional tasks was divided by the straight running time, it should provide greater ratios for injured than for uninjured subjects. An injured person who was so fast that his/her performance in this test would probably be considered within normal parameters, could not have normal results if this ratio procedure were applied. The procedure had the objective of decreasing the influence of individual factors such as speed and agility, from the test results.

Once the times of the three running tasks were obtained, the results were transformed into two different ratios:

$$R_1 = \frac{\text{Figure 8 Running Time}}{\text{Straight Running Time}}$$

$$R_2 = \frac{\text{Slalom Running Time}}{\text{Straight Running Time}}$$

In order to withdraw any effect of the brace in the straight running when assessing the effectiveness of the Generation II® brace, two other ratios were created.

$$R_3 = \frac{\text{Figure 8 Running Time (brace)}}{\text{Straight Running Time (without brace)}}$$

$$R_4 = \frac{\text{Slalom Running Time (brace)}}{\text{Straight Running Time (without brace)}}$$

A fifth ratio (hop index) was also obtained for the hop test (task four) with the objective of normalizing the results for all subjects:

$$R_5 = \frac{\text{Normal Leg Hop Distance}}{\text{Injured Leg Hop Distance}}$$

D. ETHICAL CONSIDERATIONS

Subjects were informed of the nature of the study and its potential risks. The testing was conducted on one occasion for each subject for less than one hour. The subjects were told that they were free to withdraw from the study at any time without prejudice or coercion (see Appendix 2)

All records and data from this study were kept strictly confidential. The subjects in this study were also told that they would be referred to only by subject number in any presentation of the data of the study.

E. STATISTICAL ANALYSIS

One way analysis of variance (ANOVA) was used to test whether the means of each group differed significantly (level of significance = 0.05). It examined the hypothesis that:

a) subjects sustaining knee injuries would spend significantly more time in the performance test than normal subjects.

One way Anova and paired T-tests (level of significance = 0.05) were calculated to test the hypothesis that:

b) subjects wearing functional braces would spend significantly less time in the performance tests than when they were without braces, but more time than normal subjects.

Pearson Product Moment Correlations tested the hypotheses that:

c) the results obtained in the performance tests would correlate significantly with the Lysholm knee scoring scale.

d) the results obtained in the performance tests would correlate significantly with the KT-1000® knee ligament arthrometer measurements.

When the significance of the F ratio was established, a post-hoc test (Newman Keuls) was used to identify specific pairs of means between which the difference was statistically significant. Two One Way ANOVAs and One t-Test were performed for each task and ratio (R_1, R_2 R_3, R_4, and R_5) obtained in the study.

CHAPTER IV

RESULTS

The present study examined the performance of ACL-deficient subjects in four different tasks, namely: straight running, figure of eight running, slalom circuit running, and hop test. The results of each task are presented in this chapter. The first part consists of a description of the subjects' characteristics. The second part reports the results and analysis obtained in each task and the ratios obtained from them. Finally, the results achieved in the performance tests were correlated with the results obtained by the Lysholm knee scoring scale and the KT-1000® knee ligament arthrometer.

SUBJECTS CHARACTERISTICS

Thirty volunteers diyided into 3 groups of 10 (5 male and 5 female) participated in the study. The 3 groups (control, anterior cruciate ligament deficient, and brace wearers) were matched in five different variables: sex, age, weight, height, and activity level. The mean and standard deviation for age, weight and height are presented in Table 1. Table 2 shows the frequency distribution of sex and activity level in each of the 3 groups.

PERFORMANCE TESTS RESULTS

A) Straight running, Figure of eight and Slalom circuit

One Way ANOVA examined the difference in the running time in each of the test tasks among the control group (CONTROL), ACL-deficient group who normally do not use braces (ACL-DEFICIENT), and brace wearer group when performing without braces (NON-BRACE). Comparisons among these groups concerning the time spent in

the straight running, slalom running, and figure of eight running revealed no significant differences.

TABLE 1

Age, Height and Weight For Control, ACL-Deficient and Brace Groups

GROUPS		AGE	HEIGHT	WEIGHT
		(Yrs)	(m)	(Kg)
CONTROL (N=10)	mean	25.2	1.74	68.2
	S.D.	± 5.96	± 0.08	± 10.93
ACL-DEFICIENT (N=10)	mean	25.5	1.72	71.7
	S.D.	± 7.72	± 0.06	± 11.39
BRACE (N=10)	mean	23.7	1.77	71.3
	S.D.	± 5.72	± 0.09	± 12.06

TABLE 2

Frequency of Sex and Activity Level for Control, ACL-Deficient and Brace Groups

SEX		MALE				FEMALE			
ACTIVITY LEVEL		COMP.	RECRE.	WEEK.	SEDEN.	COMP.	RECRE.	WEEK.	SEDEN.
GROUPS	CONTROL	0	2	1	2	1	3	0	1
	ACL-DEF.	0	2	1	2	2	2	0	1
	BRACE	0	4	1	0	1	3	0	1

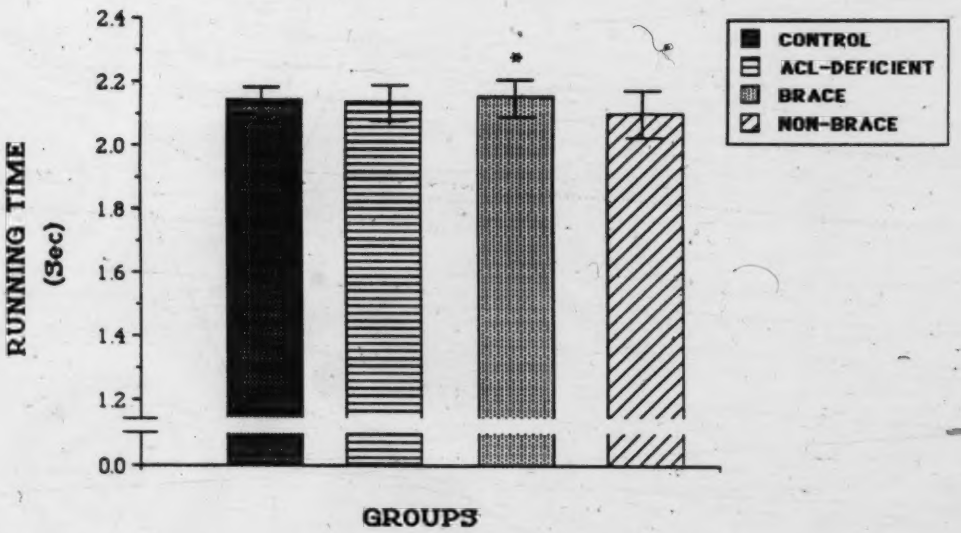
COMP. = Competitive activity level
RECR. = Recreation activity level
WEEK. = Weekend activity level
SEDEN. = Sedentary
ACL-DEF. = ANTERIOR CRUCIATE LIGAMENT-DEFICIENT

A second One Way ANOVA performed among the control group, ACL-deficient group, and brace wearer group performing with braces (BRACE), showed that the groups did not differ significantly in the straight running, slalom, and figure of eight circuits. In addition, paired t-Tests compared the results of the brace group when performing the above mentioned tasks with and without a brace. No statistically significant difference was found between the groups concerning the slalom circuit. However, the brace group performed significantly faster ($p = 0.05$) in the figure of eight, but significantly slower ($p = 0.05$) in the straight running, with brace than without brace. Figures 9 to 11 show the mean running time and standard error of the mean (SE) for each group in the straight running, slalom, and figure of eight tests.

The ANOVA's F value and probability of each situation is reported in Table 3 and 4. Table 5 illustrates the results of the paired t-Tests.

FIGURE 9

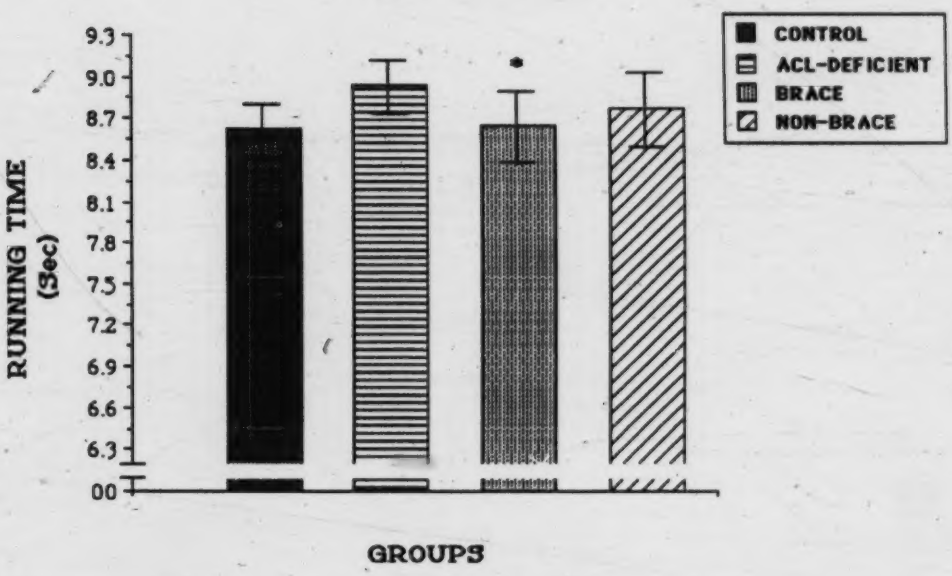
Time for Straight Running Test Results for CONTROL, ACL-DEFICIENT, and BRACE Group with and without Brace (Mean and Standard Error of the Mean)



* Significantly different from non-brace situation (p=0.05)

FIGURE 10

Time For Figure of Eight Test Results for CONTROL, ACL-DEFICIENT, and BRACE Group with and without Brace (Mean and Standard Error of the Mean)



* Significantly different from non-brace situation (p=0.05)

FIGURE 11

Time For Slalom Test Results for CONTROL, ACL-DEFICIENT, and BRACE Group with and without Brace

(Mean and Standard Error of the Mean)

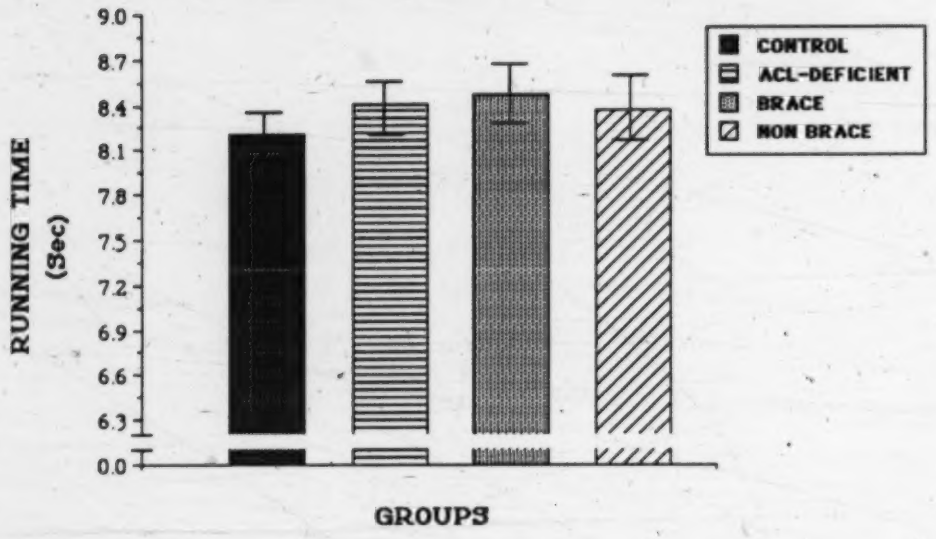


TABLE 3

One Way ANOVA Results for CONTROL, ACL-DEFICIENT and NON-BRACE Groups

TASKS	F VALUE	PROBABILITY†
STRAIGHT RUNNING	0.16	0.85
SLALOM CIRCUIT	0..35	0.71
FIGURE OF EIGHT	0.57	0.57

† Significance level = 0.05

TABLE 4

One Way ANOVA Results for CONTROL, ACL-DEFICIENT and BRACE Groups

TASKS	F VALUE	PROBABILITY†
STRAIGHT RUNNING	0.05	0.95
SLALOM CIRCUIT	0.59	0.56
FIGURE OF EIGHT	0.71	0.50

† Significance level = 0.05

TABLE 5

Paired T-tests results: BRACE Vs NON-BRACE Situation For ACL-Deficient Individuals

TASKS	T VALUE	PROBABILITY†
STRAIGHT RUNNING	2.31	0.05*
SLALOM CIRCUIT	1.22	0.25
FIGURE OF EIGHT	-2.26	0.05*

† Significance level = 0.05
* Significant

B) Ratio results

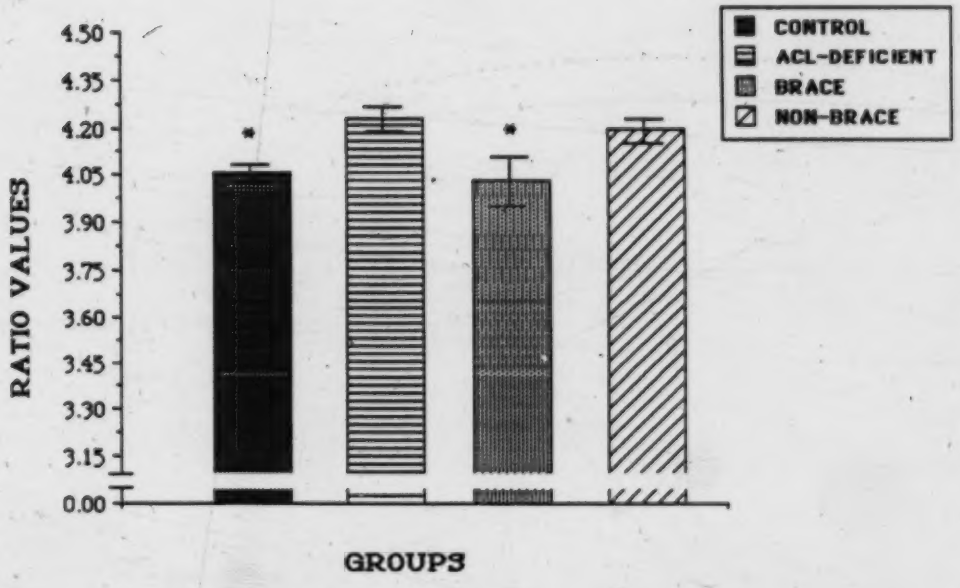
The results in the performance tests were converted into ratio values to decrease the influence of the subjects' individual speed and agility. Ratio 1 (R1) was defined as the ratio between the time spent in the figure of eight and the straight running time. Ratio 2 (R2) was defined as the ratio between the time spent in the slalom circuit and the straight running time. When this procedure was applied, the One Way ANOVA showed a significant difference in R1 ($p = .004$). Post hoc analysis (Newman Keuls) showed a significant difference between the control group and the ACL-deficient group, and between the control group and the non-brace group. Comparisons of the results for R2 revealed no significant difference among groups.

A second One Way ANOVA, which included the brace group, revealed a significant difference among groups. Post-hoc analysis showed that the control and brace groups differed significantly from the ACL-deficient group ($p < 0.05$), whereas there was no significant difference between the control and brace groups. Paired t-Tests showed that the brace group achieved significantly lower R1 values when performing with braces than without braces. However, no statistically significant difference between groups was found for R2. Figures 12 and 13 illustrate the mean ratio values and the standard error of the mean obtained for each group in R1 and R2.

Tables 6 to 9 show the results of each One Way ANOVA performed for R1 and R2, and their respective post-hoc analysis. The t-Test results for brace and non-brace situations are demonstrated in Table 10.

FIGURE 12

Results of the Figure of Eight / Straight Running Time Ratio (Ratio 1) for CONTROL, ACL-DEFICIENT, and BRACE Group with and without Brace (Mean and Standard Error of the Mean)



* Significantly different from ACL-deficient group and Non-Brace situation ($p < 0.05$).

FIGURE 13

Results of the Slalom Circuit / Straight Running Time Ratio (Ratio 2) for CONTROL, ACL-DEFICIENT, and BRACE Group with and without Brace (Mean and Standard Error of the Mean)

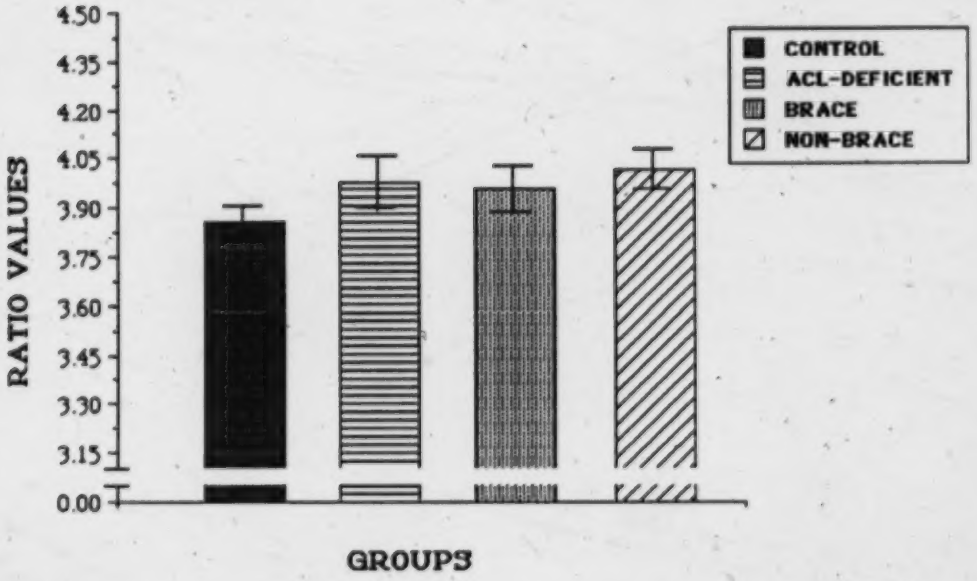


TABLE 6

One Way ANOVA Results for CONTROL, ACL-DEFICIENT and NON-BRACE Groups

RATIOS	F VALUE	PROBABILITY†
RATIO 1	6.85	0.004*
RATIO 2	1.56	0.23

† Significance level = 0.05
* Significant

TABLE 7

Post-Hoc Comparisons (Newman Keuls) Among CONTROL, ACL-DEFICIENT and NON-BRACE Groups for Ratio 1

SIGNIFICANT COMPARISONS	PROBABILITY†
CONTROL vs ACL-DEFICIENT	<0.05
CONTROL vs NON BRACE	<0.05

† Significance level = 0.05

TABLE 8

One Way ANOVA Results for CONTROL, ACL-DEFICIENT and BRACE Groups

RATIOS	F VALUE	PROBABILITY†
RATIO 1	4.55	0.02*
RATIO 2	0.92	0.41

† Significance level = 0.05
* Significant

TABLE 9

Post-Hoc Comparisons (Newman Keuls) Among CONTROL, ACL-DEFICIENT and BRACE Groups for Ratio 1

SIGNIFICANT COMPARISONS	PROBABILITY†
CONTROL vs ACL-DEFICIENT	<0.05
ACL-DEF. vs BRACE	<0.05

† Significance level = 0.05

TABLE 10

Paired t-Tests Results: BRACE vs NON-BRACE Situation for ACL-Deficient individuals

TASKS	T VALUE	PROBABILITY†
RATIO 1	-4.05	0.003*
RATIO 2	-1.1	0.30

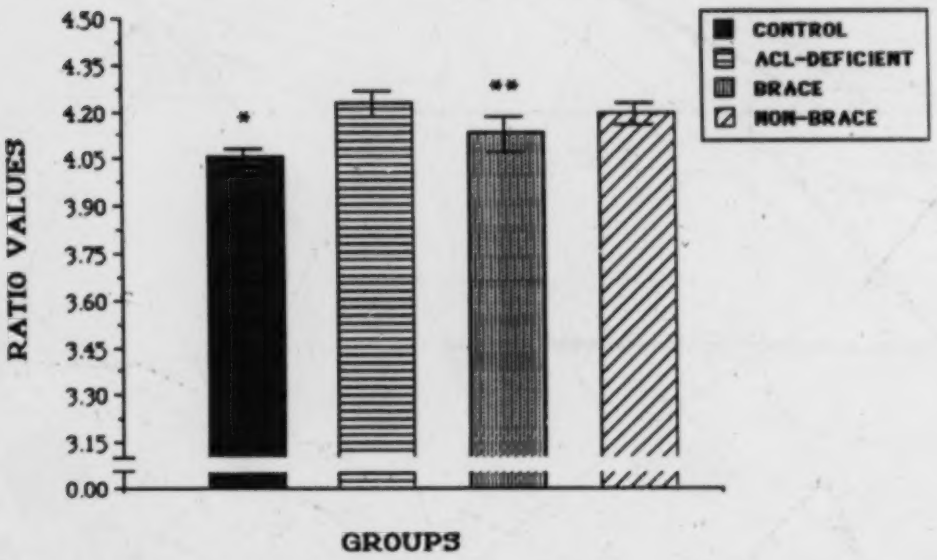
† Significance level = 0.05
* Significant

Since the use of braces caused a decreased running time in the straight running, the results of the brace group in the figure of eight and slalom circuit were also divided by the results achieved by the brace group in the straight running when tested without brace. Thus, the adverse effect of the brace on the straight running could be eliminated, providing more meaningful comparisons between groups. These new ratio values for the figure of eight and slalom were, respectively, defined as ratio 3 (R3) and ratio 4 (R4). One way ANOVA found a significant difference among groups in R3. Post hoc analysis demonstrated that the control group was significantly different from the ACL-deficient group ($p < 0.05$). However, no other significance was identified between groups. No significant difference was identified in the One way ANOVA for the R4. Paired t-Tests comparing the results of the brace group when tested with and without braces, showed that in the R3, the subjects achieved significantly better results with braces than without them. Again, no significant difference was found in the R4. Figures 14 and 15 illustrate the mean and standard error of the mean obtained for each group in the R3 and R4.

Tables 11 and 12 illustrate the ANOVA's F values, probabilities and post hoc comparisons results. Table 13 shows the paired t-Test results between the brace and non-brace situation.

FIGURE 14

Results of the Figure of Eight / Straight Running Without Brace Ratio (Ratio 3) for CONTROL, ACL-DEFICIENT, and BRACE Group with and without Brace (Mean and Standard Error of the Mean)



* Significantly different from ACL-deficient group and Non-brace situation ($p < 0.05$).

** Significantly different from Non-brace situation ($p = 0.04$).

FIGURE 15

Results of the Slalom Circuit / Straight Running Without Brace Ratio (Ratio 4) for CONTROL, ACL-DEFICIENT, and BRACE Group with and without Brace (Mean and Standard Error of the Mean)

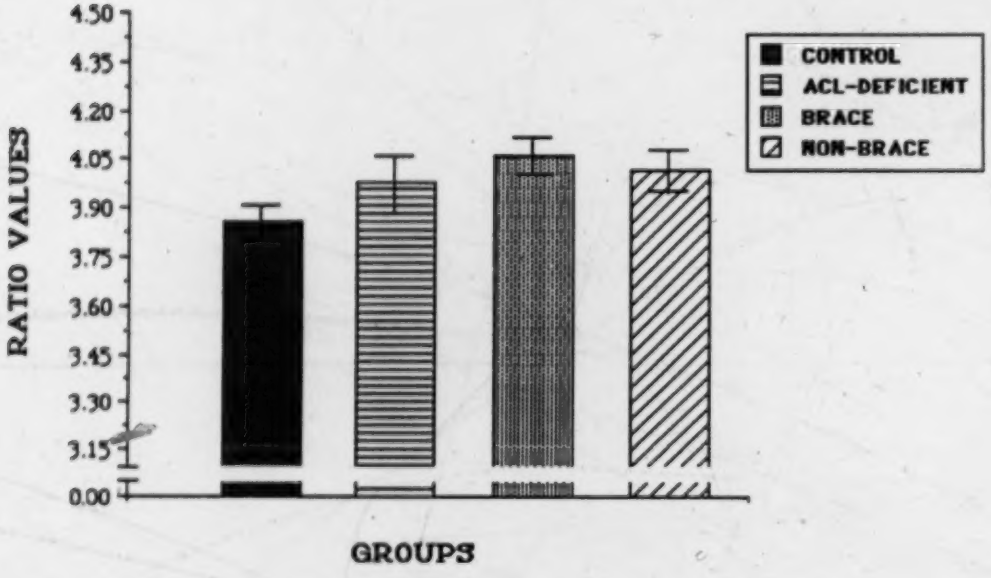


TABLE 11

One Way ANOVA Results for CONTROL, ACL-DEFICIENT and BRACE Groups

RATIOS	F VALUE	PROBABILITY†
RATIO 3	4.25	0.02*
RATIO 4	2.4	0.11

† Significance level = 0.05
* Significant

TABLE 12

Post-Hoc Comparisons (Newman Keuls) Among CONTROL, ACL-DEFICIENT and BRACE Groups for Ratio 3

SIGNIFICANT COMPARISONS	PROBABILITY†
CONTROL vs ACL-DEFICIENT	<0.05

† Significance level = 0.05

TABLE 13

Paired t-Tests Results: BRACE vs NON-BRACE Situation for ACL-Deficient individuals

RATIOS	T VALUE	PROBABILITY†
RATIO 3	-2.33	0.04*
RATIO 4	1.21	0.26

† Significance level = 0.05
* Significant

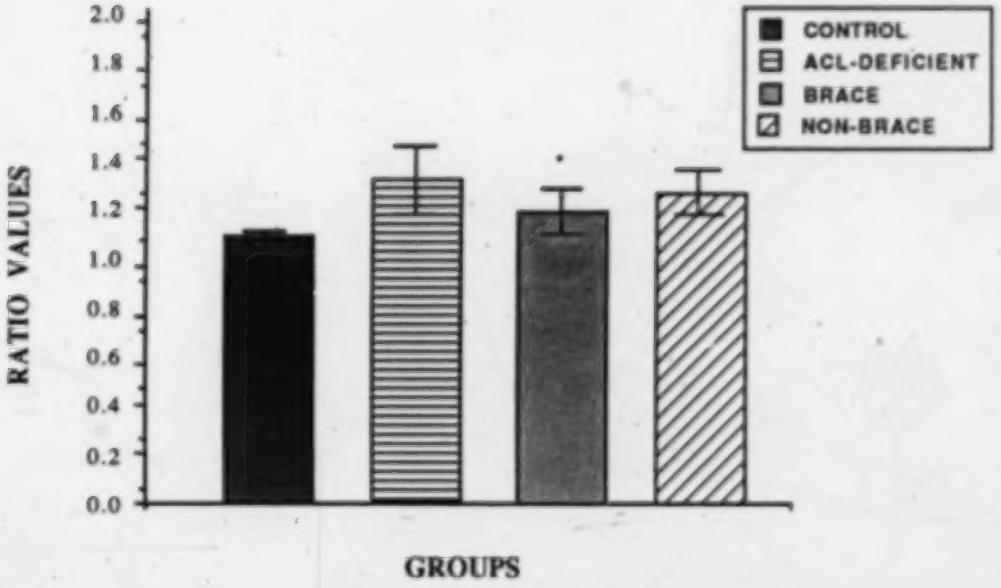
C) Hop index

A fifth ratio (R5), defined as the hop index, was used to analyze the results obtained in the hop test. The hop index was obtained by dividing the distance achieved with the normal leg by the distance achieved with the injured leg. In normal subjects, the normal leg was considered the one which achieved the greatest distance in the test. This method was used so that the ratios for normal subjects represented the greatest difference that could be obtained by them. Two One Way ANOVA's showed no significant difference among the groups in the hop index. However, a paired t-Test showed that the subjects sustaining ACL injuries achieved significantly greater distances

(p=0.05) with a brace than without a brace. Figure 16 illustrates the mean ratio values for each group in the hop test.

The ANOVA's F values and probability as well as the t-Test results are shown in table 14 to 16.

FIGURE 16
Hop Index Ratio for CONTROL, ACL-DEFICIENT, and BRACE Group with and without Brace (Mean and Standard Error of the Mean)



* Significantly different from Non-brace group (p=0.05)

TABLE 14
One Way ANOVA Results for CONTROL, ACL-DEFICIENT and NON-BRACE Groups

RATIO	F VALUE	PROBABILITY†
HOP INDEX (R5)	2.12	0.14

† Significance level = 0.05

TABLE 15
One Way ANOVA Results for CONTROL, ACL-DEFICIENT and BRACE Groups

RATIO	F VALUE	PROBABILITY†
HOP INDEX (R5)	1.87	0.17

† Significance level = 0.05

TABLE 16
Paired t-Tests Results: BRACE Vs NON-BRACE Situation for ACL-Deficient Individuals

RATIO	T VALUE	PROBABILITY†
HOP INDEX (R5)	-2.32	0.05*

† Significance level = 0.05
*Significant

LYSHOLM KNEE SCORING SCALE AND KT-1000® RESULTS

The means and standard deviation of the Lysholm knee scoring scale (LKSS), KT-1000® and the end point compliance index from the KT-1000® results are presented for each group in Table 17.

TABLE 17

Means and Standard Deviation Results for the Lysholm Knee Scoring Scale, KT-1000®, and End Point Compliance Index (EPCI)

GROUPS		LYSHOLM	KT-1000	EPCI
			(mm)	(mm)
CONTROL (N=10)	mean	99.3	0.6	0.85
	S.D.	± 2.21	± 0.77	± 0.24
ACL-DEFICIENT (N=10)	mean	60.6	5.12	2.47
	S.D.	± 17.82	± 3.47	± 1.12
BRACE (N=10)	mean	68.12	5.44	2.03
	S.D.	± 14.18	± 2.69	± 0.99

The Lysholm knee scoring scale values represent a questionnaire score (maximum = 100)

CORRELATIONS AMONG THE LYSHOLM KNEE SCORING SCALE, KT-1000® AND THE PERFORMANCE TEST

Pearson product moment correlations were used to assess the relationship among the results achieved in the performance test with the results in the Lysholm knee scoring scale and with the KT-1000® knee ligament arthrometer. Since these measurement tools were devised to evaluate ACL-deficient subjects, only the results obtained by subjects sustaining anterior cruciate ligament injuries from the ACL-DEFICIENT group and the non-brace situation of the brace group were used in the analysis. The correlation coefficients comparing the KT-1000® and LKSS results with

the performance test results ranged from r = 0.01 to 0.62. Table 18 illustrates these results. Any significance found between variables is indicated.

TABLE 18

Correlation Matrix for the Performance Test, Lysholm Knee Scoring Scale, and KT-1000

	STRAIGHT	FIGURE 8	SLALOM	RATIO 1	RATIO 2	HOP INDEX	LYSHOLM	KT-1 000	KT (EPCI)
STRAIGHT	1							N	
FIGURE 8	.93	1							
SLALOM	.75	.79	1						
RATIO 1	-.12	.25	-.17	1					
RATIO 2	-.41	-26	.29	.39	1				
HOP INDEX	.59	.51	.63	-.16	.01	1			
LYSHOLM	-.18	-.25	-.32	-.22	-.15	-.53**	1		
KT-1000	-.11	-.07	.28	-.08	.23	.60**	-.30	1	
KT (EPCI)	.35	.25	.28	-.25	.02	.47*	-.62**	.36	1

* denotes significance at 0.05 level
** denotes significance at 0.01 level

CHAPTER V
DISCUSSION

This study had two major objectives. The first objective was to validate a performance test designed to obtain precise data on knee function. To accomplish this objective, the results obtained in the performance test was compared among three different groups, namely: control, ACL-deficient, and brace. This procedure assessed the ability of the performance test to identify the injured subjects from normals (discriminative validity). Furthermore, these results were correlated with other measures normally used to assess the functional status of subjects sustaining knee injuries. Thus, this study examined if the performance tests measured the same variable (knee function) as the Lysholm knee scoring scale and KT-1000® knee ligament arthrometer (concurrent validity). The final objective of this study was to use the test to assess the effectiveness of the Generation II® brace in controlling knee instability and improving the performance of ACL-deficient subjects.

This study found no significant difference between ACL-deficient and normal subjects concerning the performance in the straight running task. This finding is in agreement with the studies by Czerniecki et al. (1988), Tibone et al. (1986), and Tegner et al. (1986). These authors observed that an ACL injury did not impair activities in a straight forward direction, when no decelerating movement was required. The findings from the present study support this finding for most of the subjects. However, some subjects with severe ACL instability, as measured by the Lysholm knee scoring scale (LKSS), were not able to perform the straight running as well as the control group. This observation suggests that a severe injury to the ACL may lead to instability even in simple functional tasks, such as straight running. Another possibility for this decreased running speed observed in some subjects was that these subjects could have had other

associated injuries, such as meniscal involvement, that were not identified at the time of the assessment.

Surprisingly, the slalom circuit was the least sensitive indicator of ACL-deficiency. The analysis of the results revealed that the groups did not differ significantly from each other in the slalom task. Even when the ratio between the slalom and the straight running (R2) was applied, no significant difference among groups could be detected. The explanations as to why ACL-deficient subjects could perform at the same level as the control group in this task may reside in the fact that the slalom test requires not only knee stability but also skills, such as motor-coordination and agility. The R2 results presented greater variability among normal subjects (S.D.=0.17) as compared to the R1 (S.D.=0.08). This finding suggests that the slalom test is more difficult to perform than the figure of eight, even for normal subjects. The slalom test is a complex test which involves several accelerating, decelerating, and cutting situations. Such a complex task may be the reason for the lack of significant difference among groups, by making skills as important as the integrity of the knee in executing the test.

Initially, the results in the figure of eight test showed no significant difference among groups. However, when these results were converted into a ratio format, the analysis showed that the control group was significantly different from the ACL-deficient and the non-brace groups. Based on these results, it is plausible that individual factors, such as speed and individual abilities, could affect the results. Since no significant difference was identified by the figure of eight test, the use of the performance test results, without being converted into ratio values, might not be a valid procedure. In the studies by Tegner et al. (1986) and Elmquist et al. (1988), as well as in the present study, several ACL-deficient subjects could perform the test at the same level as the normal subjects. Thus, no statistical significant difference among groups could be detected in all tasks executed. Conversely, the use of the ratio between the

figure of eight and straight running (R1) demonstrated the expected difference among groups.

The results showed that R1 was the best indicator of ACL-deficiency. Tegner et al. (1986) reported that the figure of eight running did not depend on general skill. They observed that soccer players of different divisions and skills performed the task in the same manner. The main difference between the figure of eight test and the slalom test, and consequently between R1 and R2, is that the figure of eight does not require as much skill to perform the turns as the slalom. Thus, a valid performance test must avoid any confounding variables, such as speed and individual skill.

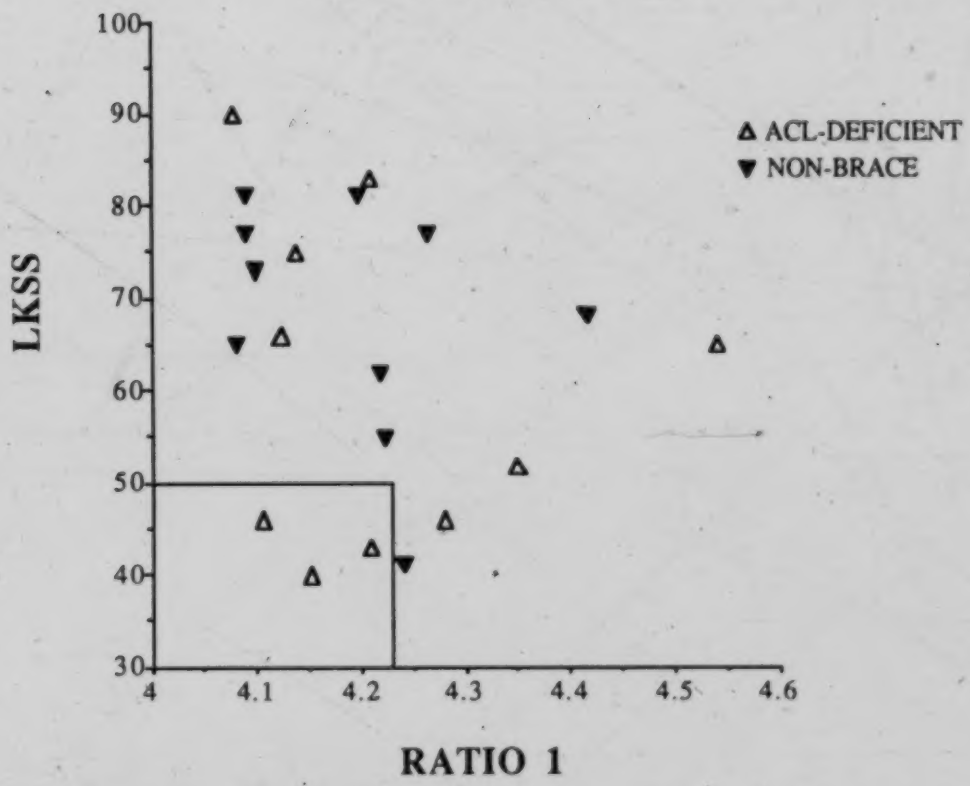
An interesting finding in this study is that the results of R1 did not correlate with the results obtained in the LKSS. Since the LKSS was devised to measure knee function (Lysholm and Gilquist, 1982), it was expected to be correlated with the results of R1. The lack of relationship between these two measurement tools may be explained on the basis that some subjects who performed poorer on the LKSS tended to have slower straight running time. This finding means that subjects sustaining severe injuries to the ACL tended to have the straight running time affected. The use of the ratio was based on the assumption that ACL injury would cause no alteration in straight running. However, the decreased straight running time observed in some injured subjects caused them to have slightly lower ratio values than expected. An analysis of the scattergram (Figure 17) between R1 and the LKSS demonstrates the effect of the decreased straight running time of subjects who had lower LKSS scores on the ratio 1.

The hop index (R5) results showed no statistically significant difference between normal and injured subjects. However, due to the small sample size (N=10), it could be speculated that a significance might be attained if more subjects were used. It is interesting to note that, although the hop index was not an indicator of ACL deficiency, the test correlated significantly with the LKSS and KT 1000 (KSS - r=0.53, and KT-1000® - r=0.64). In contrast to the ratio (R1) for the figure of eight results, the

subjects with greater ACL deficiency as noted by the LKSS and KT-1000® tended to have higher hop index results. R1 was effective in identifying subjects with little functional disability but failed with those severely injured, whereas the hop index was only able to accurately identify the subjects sustaining severe injuries to the ACL. These findings suggested that the use of the hop test (R5) in conjunction with the figure of eight test (R1) in clinical settings, to evaluate the functional status of subjects sustaining ACL injuries, would be a invaluable approach, since the tests seem to complement each other.

Figure 17

Scattergram Between Ratio 1 and Lysholm Knee Scoring Scale (LKSS) Showing That the Longer Running Time of Some Injured Subjects Caused Lower Ratio Values



Lines indicate subjects with low LKSS results who achieved lower ratio 1 results than expected

One of the most common methods of evaluating knee function has been the quantification of knee laxity. The influence of the amount of knee ligament laxity on the functional status of ACL-deficient subjects has received great attention by several investigators (Noyes et al., 1980; Seto et al., 1988; Odensten et al, 1984; Shields et al.,1984; Harter et al., 1988). The results reported in the literature, to date, may be considered somewhat controversial. Although Odensten et al (1984) have regarded knee stability as being essential for higher functional performances, most of the studies have shown that these variables are independent of one another (Seto et al., 1988; Shields et al.,1984; Harter et al., 1988). The present study shows that, when measuring the difference in displacement between both legs and the difference between the displacement at 15 and 20 pounds (EPCI), only the EPCI results were significantly correlated with the LKSS scores. Conversely, Harter et al. (1988) found a very low correlation between the EPCI and their knee scoring scale (r=-0.05). The differences in the knee scoring scales used by both studies may account for the differences between these findings. Moreover, the poor relationship between the increased laxity in the injured leg and the LKSS scores suggests that one variable may be independent from the other.

More interesting results were obtained when comparing the KT- 1000 with the functional tests. Apart from the correlation with the hop test, all the other tests presented very low coefficients. The lack of significant correlation may be explained in terms of the inadequacy of the KT-1000® and ligament tests in reproducing the forces normally found in the everyday life activities (Noyes et al., 1980). These findings reinforce the idea that the results obtained in instrumented clinical tests were unrealistic, due to the difference between clinical tests and athletic activities situations. Therefore, the patient's functional status should not be predicted on basis of instrumented clinical tests.

The significant correlation coefficient obtained between the KT-1000® and hop index was not surprising. Odensten et al., (1984) reported that the hop test results were

correlated with muscle strength and that muscle strength was dependent on knee joint stability. Therefore, muscle strength could be a common point between these two variables. Unfortunately, the present study cannot substantiate this assumption.

The most typical method of assessing knee function has been the use of knee scoring scales. This rating system has been regarded as the most reflective factor of knee functional status (Harter et al., 1988). Except for the the hop index, the findings from this study showed a low correlation between the LKSS and the functional tests, with coefficients ranging from -0.36 to -0.16 . Tegner and Lysholm (1985) observed that although a performance test is an objective way of measuring function, knee scoring scale scores provide a better picture of knee function by evaluating the patient "seven days a week" as opposed to a short test situation. However, the most common criticism for the knee scoring scales has been their lack of objectivity with tendency to overestimation or underestimation of the test scores according to the activity level of the patient (Odensten et al., 1984; Noyes et al.,1985).

A possible cause for the poor relationship between the LKSS and R1 (best performance test indicator of ACL-deficiency) was explained earlier in this chapter. However, the lack of a relationship between this scale and the performance test results raises two alternative possibilities. First, the two assessment tools measured different functions. For instance, the LKSS would be more related to the way the patient perceives his/her disability, or the performance test would be associated with the patient's physical attributes and confidence level to perform the test. Secondly, one of the two instruments may not measure knee function. Therefore, either the knee scoring scale or the performance test might be a faulty way of assessing the functional status of subjects sustaining knee ligament injuries. Since there is no "gold standard" for measuring knee function, this issue remains to be answered by future studies.

An important part of this study was to assess the effectiveness of a functional brace (Generation II®) in improving the functional performance of subjects sustaining

knee injuries. Thus, 10 subjects who normally use functional braces for athletic activities performed the tests with and without braces and their results were used for comparisons. Previous reports in the literature showed that some braces may hinder the performance by decreasing running speed and agility (Tegner et al., 1988; Houston and Goemans, 1982 ; Prentice and Toriscelli, 1986). However, the only study which examined the effect of braces on the performance of injured subjects was that of Houston and Goemans (1982). It was observed in this study that there was a marked performance reduction caused by the braces during knee extension and stair run tests. The authors suggested that braces had a damping effect, absorbing force output by muscles around the knee joint. In the present study, similar results were found for the straight running and slalom circuit. Although no significant difference was found in the slalom circuit, the brace group spent significantly more time in the straight running task. Moreover, Prentice and Toriscelli (1986) also found that braces may adversely affect forward running speed in healthy subjects.

The somewhat surprising results obtained in the slalom circuit suggest that the Generation II® brace did impair the subjects' performance in more complex maneuvers. It seems logical to think that the feeling of security given by the brace could be a result of decreased speed. If this statement is true for complex tasks such as the slalom test, the same can not be said about the figure of eight. In this task, the brace group performed significantly better than the non-brace group. This finding suggests that the Generation II® brace provided sufficient stability enabling the subjects to compensate for the injury or any impairment caused by the brace. However, it limited the performance on tasks involving more complex maneuvers or during the straight running.

The results provided by Ratio 1 showed that the Generation II® brace was so efficient in reducing the instability that the brace group was similar to the control group and significantly better than the non-brace and ACL-deficient groups ($p<0.05$). The

results reinforce the idea that in less complex maneuvers, the Generation II® brace provided stability and confidence to the subjects without impairing the movement to any great degree.

The brace group results in the figure of eight and slalom circuit were also divided by the results obtained in the straight running when tested without brace. This procedure had the objective of withdrawing the adverse effect of the brace in the straight running. It provided normalized results that yielded more meaningful comparisons with the other groups. As opposed to the previous ratio 1 results, these findings showed no significant difference between the brace group and control or ACL-deficient groups. Although not statistically significant, the brace group was closer to the control group than the others. Furthermore, in this analysis, the brace group performed significantly better than the non brace group. This finding shows that the satisfactory results in R1 were caused by an improved performance in the figure of eight task, instead of only by a decreased performance in the straight running. Applying the ratios to the slalom test did not change the results previously obtained in the slalom circuit. Both the R2 and the R4, could not detect any significant difference among groups.

In the hop test (R5), a significant difference was found between the brace and non brace situations . Tegner et al. (1985) reported that the use of braces in uninjured athletes did not affect their performance. Thus, no impairment in performance was expected. The findings of the present study showed a positive effect of the brace on the distance achieved by the injured subjects. Therefore, the use of the Generation II® brace by the brace group gave, at least, some confidence to these subjects to achieve greater distances in the hop test.

The conclusions by Houston and Goemans (1982) that the benefits of functional braces were caused by reduced performance need to be reexamined. In their study, the tasks used did not involve situations, such as turning and jumping, in which the brace could play a significant role. Thus, they did not evaluate the effect of the braces in

decreasing instability. Rather, the investigators looked at the brace effect on the performance in tasks where braces were not necessary. The present study showed that the Generation II® brace actually did cause a significant reduction in speed in the straight running and a minor impairment in complex tasks such as the slalom circuit. However, its effect on controlling instability could not be denied, when the results involving the figure of eight were analyzed. In addition, the positive effect of the Generation II® brace in the hop test, suggests that despite some impaired performance, this brace was effective in providing confidence and stability for the ACL-deficient subjects.

CLINICAL IMPLICATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The analysis of ultimate results of different treatment approaches for ACL instability are mostly based on subjective data. The performance test presented in this study proved to be able to obtain objective information on the functional status of subjects sustaining ACL injuries. The quantification of knee function may help clinicians in evaluating patients' treatment programs, by monitoring their progress. In addition, the tasks were easy to apply and accessible to clinicians and researchers interested in examining tne functional aspect of the disabilities caused by an ACL injury.

A valid performance test has several useful applications. The test presented in the present study could be used to assess the effectiveness of different treatment programs on improving knee function following a ACL injury. The performance test could also be employed to compare surgical and conservative approaches to knee instabilities, or even to compare the results of different forms of surgical intervention. Pre and post-test studies designs using this test for treatment comparisons are strongly recommended. The results of these studies would be based on objective evidence given

by the performance test results, rather than on subjective impressions, such as the patient's analysis of his/her disability.

A future point for investigation of this performance test is the analysis of its inter-tester and intra-tester reliability. Since the test could be used for test-retest experiments, an analysis of the test or individual task reliability would be of great importance. Furthermore, some information gathered in the present study may contribute for increasing the accuracy of this test and its tasks.

During the data collection procedure, it was observed that this test was highly dependent on the subjects' cooperation. Occasionally, it was necessary to reinforce to the subjects that they were supposed to run the tasks at their maximum speed and, then, ask them to repeat the task. To increase the accuracy of the test, each subject should do each task three times and only the best time used for analysis. Doing all the tasks many times could be, however, too demanding on the subjects. Since this study demonstrated that the inclusion of complex tasks in a functional test was not useful and that the figure of eight test ratio (R1) was a valid indicator of ACL deficiency, a new test evaluation should include only the figure of eight, straight running, and hop tests.

This study dealt exclusively with patients sustaining injuries to the anterior cruciate ligament. Future research dealing with different knee injuries, such as meniscal damage or other ligament deficiency, are also suggested. However, it is worthwhile to remember that the conversion of the results into ratio format was based on the assumption that an ACL injury would not affect the straight running. Therefore, analysis of different injuries may not prove to be valid if such injuries have, indeed, an effect on the straight running time of the subjects.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The two major objectives of the present study were to validate a performance test to assess anterior cruciate deficient subjects and to use the test to evaluate the effectiveness of the Generation II® brace on controlling the knee instability of these subjects. To accomplish these objectives, 30 subjects were divided into 3 groups of 10 (Control, ACL-deficient and brace groups), then tested in four different tasks (straight running, slalom circuit, figure of eight running, and hop test). The results achieved by the subjects in the slalom circuit and figure of eight running tasks were divided by their time obtained in the straight running task (ratio 1 and 2). This procedure had the objective of reducing the influence of individual factors such as speed and skill. Furthermore, all subjects had their knee ligament laxity tested by the KT-1000® knee ligament arthrometer and their knee functional status assessed by the Lysholm knee scoring scale.

One way analyses of variance were calculated for all the tasks to compare the results obtained by each group, while paired t-Tests compared the differences between the brace group when the subjects were tested with and without braces. Pearson product moment correlations were also used to examine any relationship between the results obtained in the performance tests and the results obtained by the Lysholm knee scoring scale and the KT-1000® knee ligament arthrometer.

The following conclusions can be taken from the study above described:

1. Injuries to the anterior cruciate ligament do not affect activities executed in a straight forward direction (straight running) for a ten meter distance, unless a severe injury, or an associate injury, is present.

2. Functional tests should not include complex activities, such as the slalom test. Complex tasks reduce the validity of the test, by making the skill to execute such a task as important as the functional capability to perform the task.

3. The figure of eight ratio (Ratio1) was the only test variable able to detect a significant difference between normal and ACL-deficient subjects (best indicator of ACL deficiency). It showed that the performance test results could, indeed, be affected by individual factors such as speed and skill. The use of the performance test results without being converted into ratio values did not differentiate groups.

4. In clinical practice, the figure of eight test (Ratio 1) and the hop test (Ratio 5) could be used in conjunction with each other to provide objective data on the functional status of ACL deficient subjects.

5. Knee ligament laxity, as measured by the KT-1000® knee ligament arthrometer, was poorly related with the functional tests. Therefore, this measure should not be used to make inferences on the functional status of patients sustaining knee ligament injuries.

6. Since the Lysholm knee scoring scale and the performance tests did not relate to each other, further research is needed to assess which of these instruments is a more precise measure of knee function.

7. Despite some performance hindrance on the straight running and slalom circuit tasks, the Generation II® brace was effective on improving the functional performance of ACL deficient subjects.

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APPENDIX A

LYSHOLM KNEE SCORING SCALE

NAME:_____ SUBJECT #:_____

AGE:_____ SEX:_____

WEIGHT:_____ HEIGHT_____

ACTIVITY LEVEL:

- COMPETITIVE SPORTS ☐
- RECREATIONAL SPORTS ☐
- WEEKEND SPORTS ☐
- SEDENTARY ☐

LYSHOLM KNEE SCORING SCALE

LIMP (5 points)

- None _____ 5 ☐
- Slight or periodical _____ 3 ☐
- Severe and constant _____ 0 ☐

SUPPORT (5 POINTS)

- Full support _____ 5 ☐
- Stick or crutch _____ 3 ☐
- Weight bearing impossible _____ 0 ☐

STAIR CLIMBING (10 POINTS)

- No problems _____ 10 ☐
- Slightly impaired _____ 6 ☐
- One step at a time _____ 2 ☐
- Unable _____ 0 ☐

SQUATTING (5 POINTS)

- No problems _____ 5 ☐
- Slightly impaired _____ 4 ☐
- not past 90° _____ 2 ☐
- unable _____ 0 ☐

TOTAL _____ ☐

See page 2

WALKING, RUNNING AND JUMPING (70 POINTS)

A. INSTABILITY:

Never giving way	30 ☐
Rarely during athletic or other severe exertion	25 ☐
Frequentely during athletic or other severe exertion (or unable to participate)	20 ☐
Occasionally in daily activities	10 ☐
Often in daily activities	5 ☐
Every step	0 ☐

B. PAIN:

None	30 ☐
Inconstant and slight during severe exertion	25 ☐
Marked on giving way	20 ☐
Marked during severe exertion	15 ☐
Marked on or after walking more than 2 Km	10 ☐
Marked on or after walking less than 2 Km	5 ☐
Constant and severe	0 ☐

C. SWELLING:

None	10 ☐
With giving way	7 ☐
On severe exertion	5 ☐
On ordinary exertion	2 ☐
Constant	0 ☐

ATROPHY OF THIGH (5 POINTS)

None	5 ☐
1-2 Cm	3 ☐
More than 2 Cm	0 ☐

TOTAL: ☐

APPENDIX B

CONSENT FORM

VALIDATION OF A PERFORMANCE TEST FOR OUTCOME EVALUATION OF KNEE REHABILITATION

I,_____, freely and voluntary consent to participate in this research project, under the direction of Mr. Sergio da Fonseca.

I have been told the objectives of this study and a thorough description of the procedures has been explained. I will be expected to participate on one occasion for less than one hour. I understand the tasks that I will perform and that they will place some stresses upon my knee. I know that my knee may give way during the tasks and knee swelling and soreness may occur after the test.

I am aware that I may withdraw my consent and discontinue my participation in this research at any time without prejudice to me. I authorize Mr. Sergio da Fonseca to keep, preserve, use and dispose of the findings from this research with the provision that my name will not be associate with the results.

_____

Witness Date

_____

Participant Date

I have explained and defined the research procedure to which the subject has consented to participate.

_____

Signature Date

INFORMATION SHEET

VALIDATION OF A PERFORMANCE TEST FOR OUTCOME EVALUATION OF KNEE REHABILITATION

The objective of this study is to create and validate a performance test that could assess the functional ability of people with anterior cruciate ligament injuries. At the same time, the test will be used to evaluate the effectiveness of a knee brace in the functional performance of injured people. The performance test consists of recording the time spent by people with and without knee ligament injuries while executing three different tasks: 1) running in a straight line; 2) running a figure of eight running track; 3) running a slalom circuit. The fourth task involves hopping on one leg.

During the performance test, you will be asked to run as quick as possible in each of the three running tasks, and to hop for distance in the hop test. You must be properly dressed for the test. The use of adequate running shoes and shorts (or any other running outfit which does not impair the movement) will be compulsory. You will be given a ten minute warm-up on a bicycle ergometer before the test and allowed to perform one practice at each test station.

Prior to the test, the functional level of your knee will be assessed by a questionnaire (Lysholm knee scoring scale). In addition, the laxity of your knee ligaments will be measured by a portable device which quantifies the motion between the lower leg in relation to the thigh (KT-1000® knee ligament arthrometer).

The test will place some stress upon your knee. Your knee may give way while performing the tasks. In addition, there is the possibility of swelling and/or soreness in your knee following the test execution. The chances of these possibilities are small but you should be aware they could occur. If the knee swell you are advised to apply ice to the knee for 3 fifteen minute period over a 3-5 hour period. If the swelling persists over two days, your are advised to contact Dr. D. C. Reid (432-4752).

If you do not feel capable, or confident, to perform the test, you are free to withdraw from the study at any time without prejudice. All records and data from this study will be kept strictly confidential and you will be referred to by subject number only in any publication or material that might follow. If you have any questions, they can be answered now or any time in the future by calling Sergio da Fonseca at 438-9498.

APPENDIX C

KT-1000® PROCEDURE SUMMARY[1]

Principal: In normal knee, anterior drawer coupled with medial rotation.
In normal knee, posterior force coupled with lateral rotation
Cruciate damage may uncouple this.

KT-1000® PASSIVE DRAWER TEST (ANT. X LIG)

A) Preliminary

Check knee for limited range of motion.
Make sure test at greater than 20° more than flexion block.
Thigh support placed proximal to superior pole of patella.
Distal support distal to lateral malleolus.
Ideal knee flexion 20° - 30°.
Record for reproducibility.
Make sure tibial tubercle rotation (position) equal both legs.
Mark joint line.

B) Application

First tighten distal strap.
then proximal.
Arthrometer vertical or slight ext. position.
Patella pad keep patella and femur stabilized.
Arrow should point to joint line
Adjust patella pad - slide to top of case (loosen)
Then down until arrow on dial at 10 o'clock.
Then tighten

C) Calibration

Relax quads - largest source of error.
Apply post pressure on patella pad till stabilizes.
Give momentary force on bar posteriorly then release.
Rotate dial to zero.

D) Passive Drawer Test Method

Test from end of bed, one hand on patella pad, one on bar.
Passive stretch followed by slow anterior pull.
Repeat 3 times.
Then record 4 th.
Low tone 15 lbs. pull.
High tone 20 lbs. pull.
Record both
If sudden jump possible calf bulk pressure.
Readjust proximal strap and recalibrate.

---

[1]Modified from MEDmetrics KT-1000 knee ligament arthrometer summary sheet

APPENDIX D

RAW DATA

	GROUPS	SEX	ACTIVITY LEVEL	AGE	WEIGHT	HEIGHT	STRAIGHT ...	FIGURE 8	SLALOM	HOPPING R	HOPPING L	RATIO 1	RATIO 2	HOP INDEX	LYSHOLM ...	KT -1000	EPCI	RATIO 3	RATIO 4
1	CONTROL	FEMALE	COMPETITIVE	22	57.0	1.76	2.84	8.80	7.71	79.00	77.00	3.92	3.78	1.03	100	0	.50	3.92	3.78
2	CONTROL	FEMALE	RECREATIONAL	22	60.0	1.70	2.35	9.34	9.00	64.50	65.00	3.97	3.83	1.01	100	0	1.00	3.97	3.83
3	CONTROL	FEMALE	SEDENTARY	14	67.0	1.74	2.31	9.14	8.65	63.75	64.50	3.96	3.74	1.01	93	.75	1.00	3.96	3.74
		MALE	RECREATIONAL	25	77.0	1.87	1.94	8.80	7.55	86.00	87.00	4.12	3.89	1.01	100	.25	.50	4.12	3.89
5	CONTROL	FEMALE	RECREATIONAL	27	60.0	1.70	2.25	9.02	8.15	67.25	62.25	4.01	3.62	1.08	100	0	1.00	4.01	3.62
6	CONTROL	MALE	SEDENTARY	29	80.0	1.71	1.97	8.21	7.68	88.50	94.25	4.17	3.98	1.17	100	1.00	1.00	4.17	3.98
7	CONTROL	MALE	RECREATIONAL	25	70.0	1.82	1.98	8.12	7.72	86.00	84.00	4.10	3.90	1.02	100	2.50	1.00	4.10	3.90
8	CONTROL	MALE	SEDENTARY	33	72.0	1.82	1.95	8.06	8.29	84.75	86.50	4.13	4.25	1.02	100	1.00	1.00	4.13	4.25
9	CONTROL	FEMALE	RECREATIONAL	21	53.0	1.58	2.30	9.36	8.46	64.40	64.50	4.07	3.68	1.00	100	.25	1.00	4.07	3.68
10	CONTROL	MALE	SEDENTARY	34	78.0	1.75	2.20	8.81	8.57	69.50	76.50	4.00	3.90	1.10	100	.25	.50	4.00	3.90
11	ACL	FEMALE	RECREATIONAL	17	60.0	1.81	2.09	8.62	7.65	75.50	80.90	4.12	3.66	1.07	66	4.50	1.50	4.12	3.66
12	ACL	FEMALE	COMPETITIVE	20	51.0	1.61	2.11	8.73	7.84	76.50	75.40	4.14	3.72	1.01	75	5.00	2.00	4.14	3.72
13	ACL	FEMALE	RECREATIONAL	15	60.0	1.64	2.29	9.34	8.68	64.90	62.20	4.00	3.79	1.04	90	2.00	2.00	4.00	3.79
14	ACL	MALE	SEDENTARY	29	90.0	1.80	1.93	8.26	7.73	65.00	84.50	4.20	4.01	1.30	46	8.25	2.50	4.20	4.01
15	ACL	FEMALE	COMPETITIVE	30	63.0	1.73	2.22	9.22	9.27	75.00	57.00	4.15	4.18	1.99	40	7.00	2.50	4.15	4.18
16	ACL	MALE	SEDENTARY	37	75.0	1.73	2.34	9.61	9.10	74.00	38.00	4.11	3.89	1.95	46	12.50	4.50	4.11	3.89
17	ACL	MALE	RECREATIONAL	35	85.0	1.75	2.05	9.31	8.31	74.25	68.00	4.54	4.05	1.09	65	1.00	.75	4.54	4.05
18	ACL	FEMALE	SEDENTARY	18	60.0	1.67	2.17	9.44	8.54	53.50	53.50	4.35	3.84	1.00	52	2.00	3.00	4.35	3.84
19	ACL	MALE	WEEKEND	29	81.0	1.70	2.11	8.89	8.59	71.50	58.00	4.21	4.07	1.23	43	4.00	4.00	4.21	4.07
20	ACL	MALE	RECREATIONAL	25	68.0	1.73	1.86	7.83	8.32	86.00	85.00	4.21	4.47	1.01	83	5.00	2.00	4.21	4.47
21	BRACE	MALE	RECREATIONAL	22	88.0	1.85	1.92	7.91	7.94	83.50	91.75	4.12	4.14	1.10	•	•	•	4.10	4.11
22	BRACE	FEMALE	RECREATIONAL	24	70.0	1.70	2.34	9.17	9.39	66.00	58.50	3.92	4.01	1.13	•	•	•	4.17	4.27
23	BRACE	MALE	RECREATIONAL	34	81.0	1.88	2.27	8.53	8.19	72.25	83.50	3.76	3.61	1.15	•	•	•	4.00	3.84
24	BRACE	FEMALE	COMPETITIVE	17	68.0	1.79	2.11	8.21	7.92	77.25	78.75	3.89	3.75	1.02	•	•	•	3.84	3.70
25	BRACE	FEMALE	SEDENTARY	19	59.0	1.67	2.16	9.47	9.12	63.00	56.50	4.30	4.22	1.12	•	•	•	4.44	4.28
26	BRACE	MALE	WEEKEND	31	70.0	1.79	1.97	8.50	8.33	71.50	73.00	4.31	4.23	1.02	•	•	•	4.25	4.16
27	BRACE	FEMALE	RECREATIONAL	17	58.0	1.68	1.99	8.21	8.09	68.00	72.50	4.13	4.07	1.07	•	•	•	4.19	4.13
28	BRACE	MALE	RECREATIONAL	25	91.0	1.92	2.11	8.13	8.11	80.50	99.75	3.85	3.84	1.24	•	•	•	4.00	4.00
29	BRACE	FEMALE	RECREATIONAL	27	57.0	1.68	2.52	10.40	9.61	36.25	66.50	4.13	3.81	1.83	•	•	•	4.16	3.84
30	BRACE	MALE	RECREATIONAL	21	71.0	1.76	2.02	7.75	7.76	73.50	85.00	3.84	3.84	1.16	•	•	•	4.16	4.17
31	WITHO...	MALE	RECREATIONAL	22	88.0	1.85	1.95	8.18	8.01	88.75	91.75	4.20	4.15	1.14	81	7.75	1.50	4.20	4.15
32	WITHO...	FEMALE	RECREATIONAL	24	70.0	1.70	2.20	9.29	9.23	66.00	57.00	4.22	4.20	1.16	55	2.75	2.00	4.22	4.20
33	WITHO...	MALE	RECREATIONAL	34	81.0	1.87	2.13	8.71	7.98	62.50	83.50	4.09	3.71	1.30	77	4.50	3.00	4.09	3.71
34	WITHO...	FEMALE	COMPETITIVE	17	68.0	1.79	2.14	8.76	8.23	75.00	78.75	4.09	3.85	1.05	81	3.75	1.75	4.09	3.85
35	WITHO...	FEMALE	SEDENTARY	19	59.0	1.67	2.13	9.41	9.20	63.00	50.00	4.42	4.32	1.26	68	10.00	1.00	4.42	4.32
36	WITHO...	MALE	WEEKEND	31	70.0	1.79	2.08	8.53	7.78	71.50	73.00	4.26	3.89	1.02	77	4.75	1.50	4.26	3.89
37	WITHO...	FEMALE	RECREATIONAL	17	58.0	1.68	1.96	8.31	8.11	62.75	72.50	4.24	4.14	1.15	41	7.50	4.00	4.24	4.14
38	WITHO...	MALE	RECREATIONAL	25	91.0	1.92	2.03	8.20	7.88	76.50	99.75	4.08	3.88	1.30	65	2.50	1.50	4.08	3.88
39	WITHO...	FEMALE	RECREATIONAL	27	57.0	1.68	2.50	10.55	9.58	36.25	66.50	4.22	3.83	1.83	62	8.50	3.00	4.22	3.83
40	WITHO...	MALE	RECREATIONAL	21	71.0	1.76	1.86	7.63	7.62	77.00	85.00	4.10	4.10	1.10	73	7.25	1.50	4.10	4.10